VOL. 28, NO. 2

JUNE 1954

Public Roads

A JOURNAL OF HIGHWAY RESEARCH

PUBLISHED BY
THE BUREAU OF
PUBLIC ROADS,
U.S. DEPARTMENT
OF COMMERCE,
WASHINGTON

U. S. 40 near Baltimore, Md.

Public Roads

A JOURNAL OF HIGHWAY RESEARCH

Vol. 28, No. 2 *June 1954*

Published Bimonthly

Edgar A. Stromberg, *Editor*

IN THIS ISSUE

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The printing of this publication has been approved by the Director of the Bureau of the Budget, January 5, 1952.

Estimate of User Taxes Paid by Vehicles in Different Type and Weight Groups

BY THE DIVISION OF RESEARCH
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In this article an estimate is made of the amounts of State highway-user taxes paid by vehicles of different types and general size groups. Of the total of $3,088 million of State motor-vehicle tax payments made in 1952, fuel-tax payments accounted for $1,968 million or 64 percent; registration-fee payments, $910 million or 29 percent; motor-carrier tax contributions, $64 million or 2 percent; and drivers' licenses, miscellaneous fees, etc., $146 million or 5 percent.

Comparisons established in this study show that passenger cars represented 83 percent of all motor vehicles registered, accounted for 81 percent of the traffic on our highways, and contributed 65 percent of total State road-user tax payments. If panel, pickup, and other light trucks are combined with passenger cars the percentages become 93, 89, and 74, respectively. Medium and heavy trucks and combinations accounted for 6 percent of the registrations, 10 percent of the traffic, and contributed 24 percent of the road-user payments. Tractor-semitrailers and truck-trailers included in the preceding group accounted for 1 percent of the registrations, 3 percent of the travel, and 12 percent of user-tax payments. Buses accounted for less than 1 percent of the registrations and travel, and 2 percent of the user-tax payments.

On the basis of highway-user tax payments per mile of travel, passenger cars and light trucks paid one-half cent per mile, buses paid 1.6 cents, and medium and heavy trucks and combinations paid 1.5 cents. The rate for truck combinations alone is slightly more than 2 cents per mile of travel, tractor-semitrailers paying 2.1 cents and truck-trailers, 2.7.

IN a previous article in PUBLIC ROADS [1] there was presented a comparison of the taxes imposed in different States on a selected group of vehicles. The sole purpose of that study was to compare the rates of taxes of the States. An entirely different, though related, matter is the total highway-user tax payments by the different major groups of vehicles. Information on this subject is of considerable importance to highway authorities, legislatures, and vehicle operators in determining the equitability of the total highway tax burden on various groups of vehicles and in weighing the tax burden on the group against the costs of providing highway service, and the benefits derived from the service.

The work presented here constitutes a series of estimates, and some may disagree with the methods used or the findings reached. Given better basic data, or more time for intensive study of individual phases of the estimates, modification would probably be necessary. It is believed, however, that the results are sufficiently within the areas of reasonableness and general validity to be useful.

[1] *Road user and property taxes on selected motor vehicles, 1953,* by E. M. Cope and R. W. Meadows. PUBLIC ROADS, vol. 27, No. 7, April 1953.

Although the principal value of this study lies in the findings, an outline of the data on which the study is based, together with a brief review of some of the problems encountered and the assumptions that were made, should be useful to those who may have occasion to evaluate or apply the findings.

In 1952 the States collected a net total of $1,967,831,000 in motor-fuel taxes and related fees. The total registration fees and associated revenues amounted to $1,069,439,000 but, for practical purposes, the $12,859,000 of fines and penalties received have been eliminated, leaving a remainder of $1,056,580,000. This was done on the theory that fines and penalties are not actually road-user revenues even though they are miscellaneous receipts of the highway departments in some States. State motor-carrier taxes collected during the year amounted to $64,036,000. The total of the State road-user taxes considered in this study is, therefore, $3,088,477,000.

Thus precise information is available on the amounts of State registration fees that were paid by automobiles, by trucks, and by buses. Various related fees such as drivers' and chauffeurs' licenses, title fees, etc., can be allocated to various classes of vehicles without fear of substantial error. Motor-carrier taxes can also be allocated with some degree of confidence: their payment is accounted for, primarily, by buses and heavy trucks.

At first glance, it might seem that the allocation of gasoline tax payments to the various groups of vehicles should be fairly easy; but this is not the case. To assign gasoline tax payments to the various groups of vehicles requires the determination of the amounts of travel of each group of vehicles, and this is particularly important among the groups of trucks since different rates of fuel consumption are assigned to each group. The formulation of an acceptable fuel consumption curve is in itself no small task, and relatively minor changes in the rates of fuel consumption assigned would make very substantial changes in the computed tax payments. The yield from fuel taxes accounts for approximately two-thirds of all road-user tax payments. According to the results of this study, motor-fuel taxes constitute 68.1 percent of the total State road-user taxes on automobiles, 63.7 percent of the taxes on buses, and 56.1 percent of the taxes on trucks.

Wherever reference is made in this study to State motor-fuel tax receipts, motor-fuel usage, highway use of special fuels, and State motor-vehicle receipts, the data are taken from the Bureau's published bulletin Highway Statistics 1952. Such information is given therein in tables G–1, G–21, G–25, and MV–2, respectively.

Findings of the Study

The findings of this study can best be described by referring to the summary data given in tables 1 and 2 and in figures 1 and 2, which portray the results graphically. The summary data compare the numbers of vehicles in each visual classification, the user taxes paid, vehicle-miles traveled, average payments per vehicle, and average payments per mile of travel.

Table 1 brings together the classified estimates of tax payments that are described individually in subsequent sections of this article. It will be observed that fuel-tax payments accounted for $1,968 million, or 63.7

Table 1.—Estimate of State highway-user taxes paid in 1952 by major groups of vehicles

Vehicle type	Registration fees	Motor-carrier taxes	Operators' and chauffeurs' license fees	Miscellaneous fees	Motor-fuel taxes	Total	
						Amount	Distribution
	1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*Percent*
Passenger cars	515,750	------	47,235	71,014	1,353,280	1,987,279	64.34
Buses	13,171	7,268	522	289	37,337	58,587	1.90
Motorcycles	1,769	------	102	407	4,488	6,766	.22
Camp and other light trailers	14,117	------	------	------	---------	14,117	.46
Single-unit trucks:							
Panel and pickup	83,804	------	4,436	5,966	123,156	217,362	7.04
Other 2-axle, 4-tire	18,729	------	836	1,186	31,567	52,318	1.69
2-axle, 6-tire	129,887	2,613	2,647	5,417	202,909	343,473	11.12
3-axle	27,309	225	297	1,083	17,461	46,375	1.50
All single-unit trucks	259,729	2,838	8,216	13,652	375,093	659,528	21.35
Vehicle combinations:							
Tractor-semitrailer	94,307	49,529	917	3,533	181,504	329,790	10.68
Truck-trailer	11,368	4,401	96	386	16,129	32,380	1.05
All combinations	105,675	53,930	1,013	3,919	197,633	362,170	11.73
All trucks and combinations	365,404	56,768	9,229	17,571	572,726	1,021,698	33.08
All vehicles	910,211	64,036	57,088	89,281	1,967,831	3,088,447	100.00

percent, of the total of $3,088 million of State motor-vehicle tax payments made during 1952. Registration-fee payments totaling $910 million brought in 29.5 percent; motor-carrier tax payments of $64 million provided 2.1 percent; operator- and chauffeur-license incomes provided $57 million, or 1.8 percent; and miscellaneous fees totaled $89 million, or 2.9 percent. The most natural comparison of total payments is that between passenger cars and other types of vehicles. Of the $3,088 million in State road-user taxes paid by all vehicles in 1952, $1,987 million was paid by passenger cars; $1,022 million was contributed by trucks and combinations; $59 million by buses. The remainder is accounted for by nearly $7 million assigned to motorcycles and $14 million assigned to camp, farm, and other light trailers.

Table 2 and figure 1 indicate that automobiles constituted 83.0 percent of motor-vehicle registrations in 1952 and accounted for 64.8 percent of the user taxes. Buses, relatively negligible in the gross totals, were approximately 0.3 percent of the numbers registered and paid 1.9 percent of the user-tax revenues. Trucks and combinations accounted for 16.8 percent of the vehicles and 33.3 percent of the revenues.

A somewhat different grouping of vehicles brings out the relation of numbers and payments more clearly. If the values for panels and pickups and other 4-tire trucks are added to those for automobiles, this constitutes what may be called the light-vehicle group. With this grouping, it is found that automobiles and light trucks formed 93.4 percent of the registered vehicles in 1952 and paid 73.6 percent of the road-user taxes. Medium and heavy trucks and combinations accounted for 6.3 percent of the vehicles and 24.5 percent of the user-tax payments. This finding is two-edged, in a sense. By the act of putting light trucks with passenger cars, the total of the truck contribution is diminished, but the weighting of payments in relation to numbers is increased from less than 2 to 1 to nearly 4 to 1.

Some of the figures for individual types in the visual classification are revealing. Two-axle, six-tire trucks amounted to 5.0 percent of the vehicles and their tax payments were 11.2 percent of the total. Three-axle trucks, constituting 0.3 percent of the vehicles, paid 1.5 percent of the revenues. Tractor-semitrailers, which added only 0.84 percent to the vehicle total, paid 10.8 percent of the total. Truck-trailer combinations constituted 0.08 percent of the vehicles and made 1.1 percent of the tax payments. Thus combinations as a group amounted to less than 1 percent of the vehicles but accounted for nearly 12 percent of the revenues.

In average payments per vehicle during 1952, it is found that the value for automobiles was approximately $45.50, that for buses was $404, and that for trucks and combinations was slightly less than $116. Within the truck and combination group, there is found an average payment of $47 by panels and pickups and $59 by other 2-axle, 4-tire trucks; the general average for 2-axle, 4-tire trucks was $49. Two-axle, six-tire trucks paid, on the average, $130, and 3-axle trucks about $265. The average payment for combinations as a group was $745, $746 being the average for tractor-semitrailers, and $736 for truck-trailers. Too much should not be made of the comparison between the two types of combinations, because of the wide difference in both numbers and geographical distribution. In the regrouping of vehicles, automobiles and light trucks are found to have made an average payment per vehicle of $46; the average for medium and heavy trucks and combinations was $227.

Comparisons on a vehicle-mile basis are also given in table 2 and are illustrated in figure 2. Here it is found that automobiles, which constituted 83.0 percent of the registrations in 1952, accounted for 80.9 percent of the traffic volume. This may be compared with their contribution of 64.8 percent to the total road-user revenues. If again automobiles and light trucks are combined, it is found that this group contributed 89.1 percent of the vehicle-miles and 73.6 percent of the revenues. Medium and heavy trucks and combinations accounted for 10.2 percent of the traffic volume and 24.5 percent of the revenues. Combinations taken alone provide an interesting comparison: They constituted 0.92 percent of the

Table 2.—Estimate of State highway-user taxes paid in 1952 by vehicles in different type and weight groups

Vehicle type	Motor vehicles registered [1]		Vehicle-miles traveled		Highway-user taxes paid [2]		Average rate of payment	
	Number	Distribution	Amount	Distribution	Amount	Distribution	Per vehicle	Per vehicle-mile
	Thousands	*Percent*	*Millions*	*Percent*	*1,000 dollars*	*Percent*		*Cents*
Passenger cars	43,654	82.96	409,271	80.89	1,987,279	64.78	$45.52	0.49
Buses	145	.28	3,564	.70	58,587	1.91	404.05	1.64
Single-unit trucks:								
Panel and pickup	4,629	8.80	33,971	6.72	217,362	7.08	46.96	.64
Other 2-axle, 4-tire	882	1.68	7,598	1.50	52,318	1.71	59.32	.69
2-axle, 6-tire	2,646	5.03	32,679	6.46	343,473	11.20	129.81	1.05
3-axle	175	.33	1,866	.37	46,375	1.51	265.00	2.49
All single-unit trucks	8,332	15.84	76,114	15.05	659,528	21.50	79.16	.87
Vehicle combinations:								
Tractor-semitrailer	442	.84	15,814	3.12	329,790	10.75	746.13	2.09
Truck-trailer	44	.08	1,197	.24	32,380	1.06	735.91	2.71
All combinations	486	.92	17,011	3.36	362,170	11.81	745.21	2.13
All trucks and combinations	8,818	16.76	93,125	18.41	1,021,698	33.31	115.87	1.10
All vehicles	52,617	100.00	505,960	100.00	3,067,564	100.00	58.30	.61
Regrouping of vehicle types:								
Passenger cars and light trucks [3]	49,165	93.44	450,840	89.11	2,256,959	73.57	45.91	.50
Medium and heavy trucks and combinations	3,307	6.28	51,556	10.19	752,018	24.52	227.40	1.46

[1] Publicly owned vehicles, motorcycles, and light trailers are excluded.
[2] Excludes $12,859,000 in fines and penalties, and tax payments of $14,117,000 assigned to light trailers and $6,766,000 assigned to motorcycles.
[3] Panels and pickups and other 2-axle, 4-tire trucks are grouped with passenger cars.

vehicles, traveled 3.4 percent of the vehicle-miles, and provided 11.8 percent of the revenues.

The final comparison shown in table 2 and figure 2 is that made on the basis of average road-user tax payments per mile of travel. The average payment by automobiles was 0.49 cent per vehicle-mile, or almost exactly one-half cent. Buses paid 1.64 cents per mile of travel and trucks and combinations, as a group, paid 1.10 cents. The average for all vehicles was 0.61 cent per mile of travel. When automobiles and light trucks are combined, the average payment per mile comes out exactly at one-half cent. Medium and heavy trucks and combinations, taken as a group, contributed 1.46 cents per vehicle-mile.

Among the general group of trucks and combinations, it is found that 2-axle, 4-tire trucks paid between 0.6 and 0.7 cent per mile of travel. Two-axle, six-tire trucks paid 1.05 cents per vehicle-mile, and 3-axle trucks 2.49 cents, the average for single-unit trucks being 0.87 cent. The rate per vehicle-mile for combinations as a group was 2.13 cents, tractor-semitrailers paying 2.09 cents and truck-trailer combinations 2.71.

In the interpretation of these figures it should be borne in mind that they are Nationwide totals and averages derived by processing in various ways the data reported by 48 States and the District of Columbia, each of which has its own schedule of user taxes, with the rates of payment differing widely from State to State. The vehicles of each type and size group may contribute relatively more in one State and relatively less in another. The findings of this study summarize the situation as a whole, giving approximate values of the aggregate and average payments by each vehicle group, and thereby affording comparisons of the extent to which each group shares in the total burden of State road-user taxation.

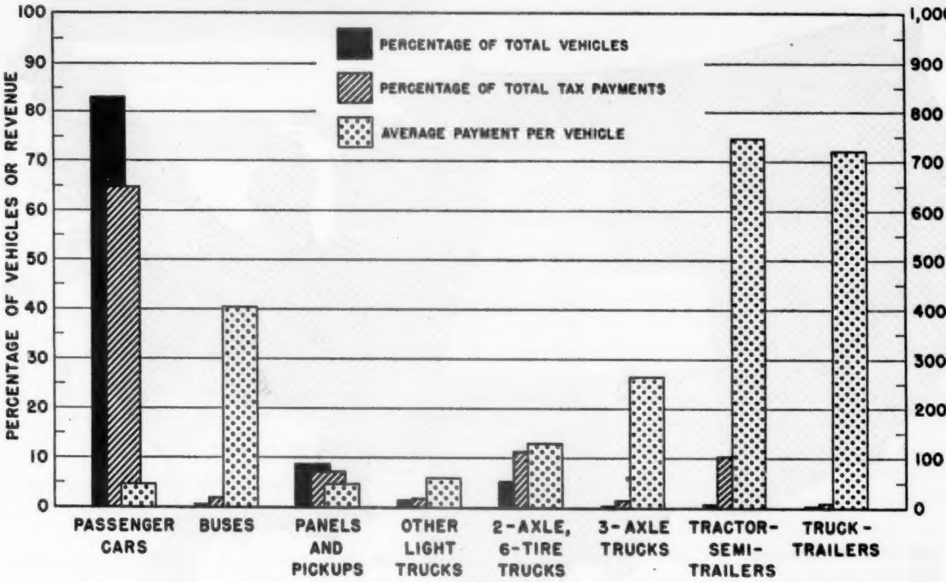

Figure 1.—Comparison of registrations and tax payments by vehicle types.

Vehicle Classifications

Gross-weight distribution

Although registrations and fee payments are segregated in State records by major types of vehicles, the further task of distributing numbers and fees among various groups of trucks is a complex matter. The differences among the various State bases of registration had to be reconciled, and, to do this, factors were developed for converting the available data supplied by the States to a gross-weight basis. Thirty-one States had furnished, for 1952, data on truck-weight or capacity groupings according to their own registration bases. In a few States this basis was the unrealistic "manufacturers' rated capacity," and in some it was on variations of net or empty weight, but for the majority, it was gross-vehicle weight. Some States use a combination of factors. Although more than half of the States now register trucks and combinations on the basis of gross weight, it can be seen in figure 3 that quite a few, including some of the larger ones, register on different bases. Conversion factors were estimated and, for each State for which data were available on some basis other than gross-vehicle weight, the conversion factors were applied to obtain an approximation of the State's registration according to the groups in which they would have fallen if all States required registration on a gross-vehicle-weight basis.

While there is no need at this point to outline those conversion factors in detail, here are some examples. Single-unit trucks of 4,500 pounds or less empty weight in States registering on an empty-weight basis were considered to be in the gross-vehicle-weight class of 1.8 times their empty weight; single-unit trucks in the 4,501–8,000-pound empty-weight group were considered to belong with vehicles of exactly twice their weight when registered on a gross-weight basis; and vehicles with an empty weight of more than 8,000 pounds were converted to gross-weight values of 2.5 times their empty weight. In States where tractor-trucks are registered on an empty-weight basis they were considered to represent combinations of 5 times the empty weight of the tractor alone; and tractors registered on a gross-weight basis were converted to gross combination weights of 1.8 times the gross registered weight of the tractor alone.

All in all, there were 18 States for which data were available on a gross-vehicle-weight basis, and it was possible to convert the data from an additional 12 States registering on other bases. However, in order to obtain balance, and because of questionable factors in the original material, data for 15 States were selected as representative. These 15 States registered more than 44.2 percent of all trucks in the United States in 1952. The percentages obtained from this 15-State sample were applied to national totals of trucks registered. This distribution is shown in table 3 (reading across) and in figure 4.

In 1952, the year on which this study is

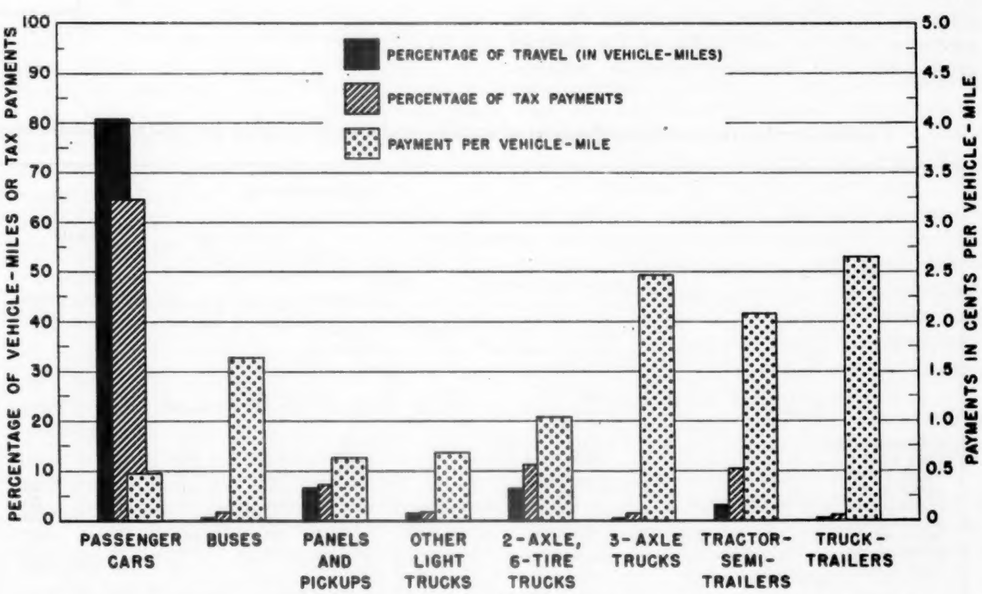

Figure 2.—Comparison of travel, tax payments, and payments per vehicle-mile.

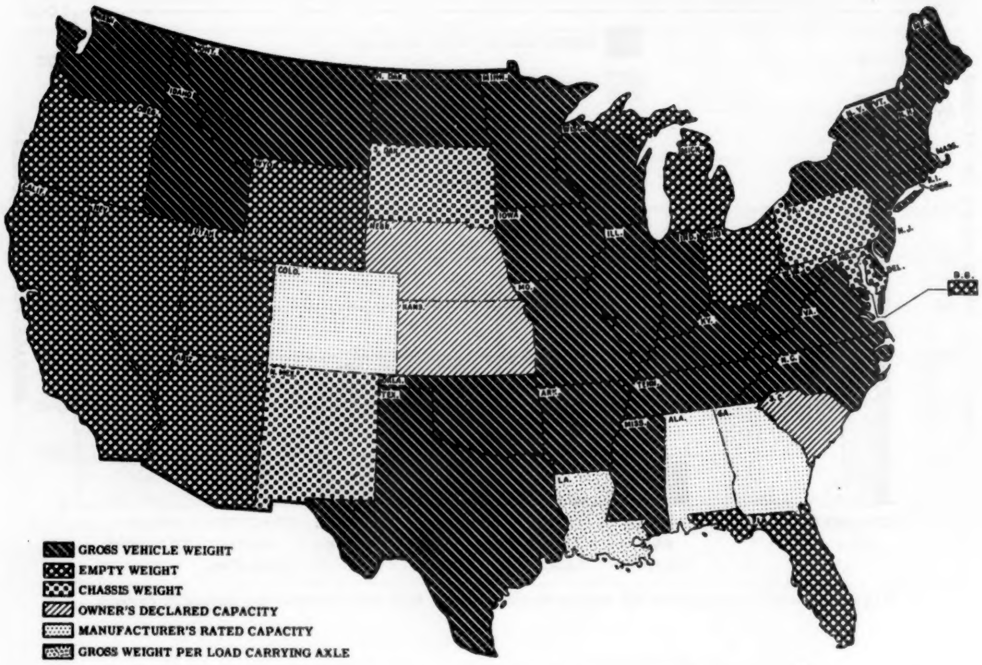

Figure 3.—Truck registration fee basis.

An entirely different problem arises in adapting the computed gross-vehicle-weight basis to the actual vehicles operating on the highway as they are observed from traffic counting or weighing stations. Determination of the taxes paid by various vehicles requires considerable knowledge of the mileages they travel; and this must be computed primarily from observation. Registration fees do not vary with the amount of travel. Motor-carrier taxes do vary to a considerable degree with the amount of travel, and fuel taxes paid vary in direct proportion as travel varies.

The "visual" classification of vehicles shown in table 3 (reading down) and in figure 5 is that ordinarily used in recording and publishing traffic-volume information. This was the principal reason dictating its adoption for this study, although another factor prompting its use was that this classification is more meaningful than is a classification based solely upon gross weight.

Although the visual classification is so commonly used in presenting traffic data, vehicles in use or registered cannot readily be classified on this basis. In spite of the fact that tractor-trucks or panels and pickups are

based, there were 8,818,000 trucks registered (excluding publicly owned vehicles). Of these, after converting to a gross-vehicle-weight basis, as described above, there were 5,679,000 in the 8,000 pounds and under group, or 64.4 percent. An additional 26.3 percent, or 2,318,000 were in the groups from 8,001 to 20,000 pounds. Only 370,000, or 4.2 percent, of the trucks were in the 20,001–30,000-pound range; and 212,000, or 2.4 percent, were between 30,001 and 40,000 pounds. The trucks and combinations of over 40,000 pounds accounted for 2.7 percent of the total, or 238,000 vehicles and combinations. Thus, only 9.3 percent of all trucks were more than 20,000 pounds gross weight.

Visual classification of vehicles

The previous discussion concerns the distribution of vehicles on registration bases, and some of the difficulties encountered in computing a uniform distribution on the basis of gross-vehicle or gross-combination weights.

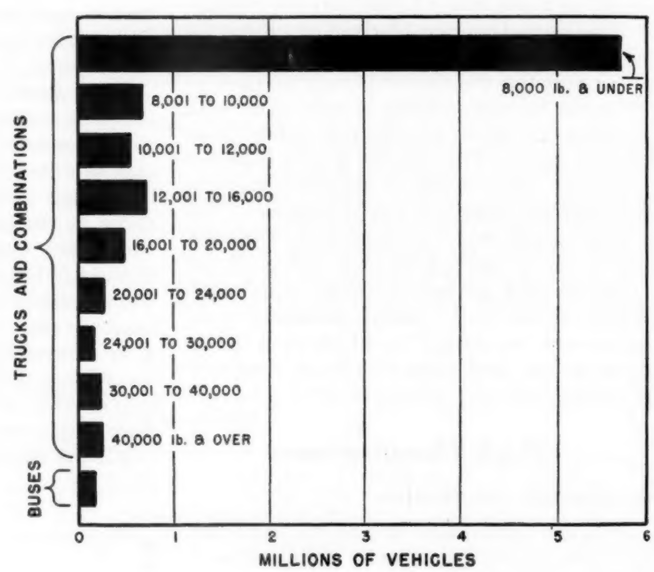

Figure 4.—Distribution of commercial vehicles by registered gross weight.

Table 3.—Estimated distribution of trucks and combinations in 1952 by visual classification and registered gross weight

Registered gross weight	Single-unit trucks								Vehicle combinations				Total	
	2-axle, 4-tire				2-axle, 6-tire		3-axle		Tractor-semitrailer		Truck-trailer			
	Panel and pickup		Other											
	Number	Distribution	Number	Distribution	Number	Distribution	Number	Distribution	Number	Distribution	Number	Distribution	Number	Distribution
Pounds	*Thousands*	*Percent*	*Thousands*	*Percent*	*Thousands*	*Percent*	*Thousands*	*Percent*	*Thousands*	*Percent*	*Thousands*	*Percent*	*Thousands*	*Percent*
8,000 and under	4,497	51.000	706	8.000	476	5.400	-----	------	-----	------	-----	------	5,679	64.400
8,001–10,000	132	1.500	88	1.000	424	4.800	-----	------	-----	------	-----	------	644	7.300
10,001–12,000	-----	------	88	1.000	441	5.000	-----	------	-----	------	-----	------	529	6.000
12,001–16,000	-----	------	-----	------	656	7.440	17	0.200	29	0.330	2	0.030	704	8.000
16,001–20,000	-----	------	-----	------	385	4.360	26	.300	29	.330	1	.010	441	5.000
20,001–24,000	-----	------	-----	------	142	1.615	18	.200	73	.825	5	.060	238	2.700
24,001–30,000	-----	------	-----	------	60	.685	26	.300	37	.415	9	.100	132	1.500
30,001–40,000	-----	------	-----	------	62	.700	65	.735	82	.925	4	.040	213	2.400
Over 40,000	-----	------	-----	------	-----	------	23	.265	192	2.175	23	.260	238	2.700
Total	4,629	52.500	882	10.000	2,646	30.000	175	2.000	442	5.000	44	.500	8,818	100.000

registered separately in a few States, there is none in which the visual classification has been adopted in a general way as a basis for vehicle registration. Manufacturers' and trade-association statistics are no more helpful; manufacturers' gross-vehicle-weight rating has understandably become the basis upon which these groups publish most of their statistics on production and sales.

As a consequence, it became necessary in preparing the visual distribution of vehicles shown in table 3 and figure 5 to resort to other sources of information. One of these was the findings of the motor-vehicle-use studies conducted in five States, as presented in the project reports made on those studies. Another was the distribution of vehicles for seven urban areas reported in the home-interview samples taken in origin and destination studies made. A third was a report prepared on an analysis of the 1952 truck registrations in North Carolina.[2] Although none of these sources provided all of the information desired, it was possible by piecing this information together with that which was available from registration records in a few States to develop the distribution shown in table 3 and figure 5.

Some of these sources also provided gross-vehicle-weight distributions of individual visual classifications. With the help of these it was possible to calculate a cross-classification of vehicles by both visual and gross-weight classifications. This tabulation, table 3, provided a means of allocating registration and related fees and taxes according to both classifications.

Registration-Fee and Carrier-Tax Payments

Registration fees and related imposts

Total revenue from State registration fees and associated imposts amounted to $1,069,439,000, or $1,056,580,000 if the $12,859,000 of fines and penalties are excluded. Of this net amount, $910,211,000 were registration fees and the remainder of $146,369,000 was accounted for by title fees and taxes, transfer and reregistration fees, operators' and chauffeurs' licenses, and other miscellaneous allied revenue. Operators' and chauffeurs' licenses alone accounted for $57,088,000.

Registration fees

In order to allocate registration fees between the various principal groups of vehicles, average registration fees were computed from the basic data on which the previous study was based.[3] Although the present study deals in national totals, it is well to remember that there are great differences among the States in their taxation of motor vehicles. Property taxes on motor vehicles are not within the scope of this study, but there is considerable variation in their imposition and magnitude also.

The average registration fee for automobiles,

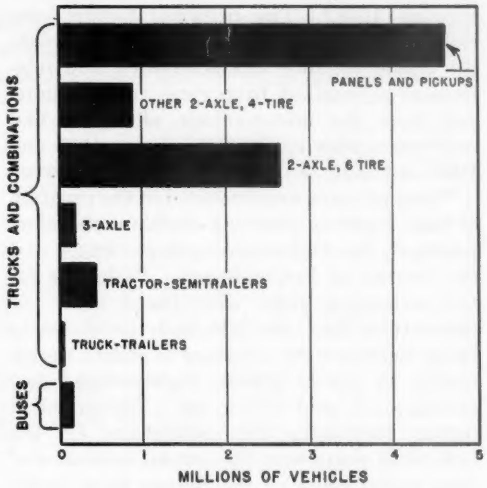

Figure 5.—Distribution of commercial vehicles by "visual" classification.

derived by simple division, is $11.81. The computed truck registration fees, derived by multiplying the numbers of vehicles in each group by the estimated average fees, yielded a total of $368,605,000, or not quite 0.9 percent more than the known total of $365,404,000. The average fees were therefore reduced 0.9 percent to arrive at the $365,404,000 total.

For 1952, truck and tractor registration fees totaled $320,251,000. To this amount was added the $59,270,000 of fees paid on various types of trailers and semitrailers, deducted from which was $14,116,000 estimated to have been paid on house trailers, light car trailers, etc. The resulting amount, $365,404,000, makes allowance for the fact that semitrailers and trailers are registered separately in many States, and that there are considerably greater numbers of semitrailers than tractors.

There were 5,679,000 trucks in the 8,000 pounds or less gross-vehicle-weight group. When converted to the visual classification, 4,497,000 fell into the panel and pickup group with 4 tires, 706,000 were other single-unit trucks with 4 tires, and 476,000 were 2-axle, 6-tire single-unit trucks. The total registration fees of these groups amounted to $103,417,000. It seems probable that the panels and pickups pay slightly smaller fees than the other vehicles in this group.

In this respect, it is interesting to note that a great many States impose lower registration fees on farm trucks than on vehicles not qualifying for that classification. The vast majority of farm trucks are in the pickup and other relatively light groups. To make allowance for this difference in fees, it was assumed that the average registration fee of the 706,000 4-tire single-unit trucks other than panels and pickups had a value of X and that the registration fee of panels and pickups had an average value of X minus 5 percent, and that the 2-axle, 6-tire vehicles in the group had a registration fee with the value of X plus 5 percent. The same technique was applied to the fees of the vehicles in the 8,001–10,000-pound group. For the 529,000 trucks in the 10,001–12,000-pound group, it was assumed that the 88,000 4-tire trucks had an average registration fee of 5 percent less than the 441,000 6-tire single-unit trucks in the group. A similar method was followed in distributing the registration fees of each of the gross-vehicle-weight classes to the visual classifications. In each instance, however, a heavier weighting factor was given to the registration fees for combinations when they fell in the same gross-weight group as single-unit trucks.

Miscellaneous fees

The allocation of operators' and chauffeurs' licenses had to be arbitrary. Some States do not require chauffeurs' licenses and others do not require ordinary operators' licenses of those who hold chauffeurs' licenses. The total chauffeurs' license fees attributed to truck operators was $9,229,000. It was assumed that one chauffeur's license at an average fee of $1.80 should be attributed to each vehicle in the gross registration weight classes of 20,000 to 40,000 pounds, and 1.5 chauffeurs' licenses should be attributed to each vehicle over 40,000 pounds. The remainder of the chauffeurs' licenses and the fees derived therefrom were attributed to trucks in the various groups under 20,000 pounds. Chauffeur license payments attributed to bus operators were computed as approximately 2 per vehicle or 290,000, and at $1.80 each these amounted to $522,000. Motorcycle operators' licenses were estimated at 25 cents per registered motorcycle, and amounted to $102,000. The remainder of operators' and chauffeurs' license payments, $47,235,000, was allocated to passenger-car operators.

After allocating operators' and chauffeurs' license revenues to various groups of vehicles, there remained $89,281,000 of miscellaneous fees to be assigned. This was done insofar as possible by examination of the individual State reports and allocating the fees to individual groups where possible. As a result of this examination of State reports, $17,571,000 was assigned to trucks. This amounted to $1.99 each. In this distribution, however, consideration was given to size and value of the vehicles since these factors affected the receipts. Title fees, transfer fees, and issuance fees were distributed to trucks on a numerical basis. Nonresident tag fees and a small amount of other miscellaneous fees were distributed between trucks on the basis of a sample distribution in five States drawn from the individual reports of the States in the Bureau of Public Roads files. The truck share of special titling taxes, amounting to $32,489,000, was distributed on the basis of gross vehicle weights, since these are ad valorem taxes and it seemed that there should be a high degree of correlation between value and weight. Undoubtedly this is susceptible of refinement, but it is probable that no great violence is done by this approach.

It was assumed that the miscellaneous revenues to be assigned to buses averaged the same as those assigned to trucks, i. e., $1.99 each, or a total of $289,000. Miscellaneous revenues of $1.00 each were attributed to the 407,000 registered motorcycles. The remaining miscellaneous fees,

[2] *Analysis of the 1952 registration of property-carrying vehicles in North Carolina.* Division of Statistics and Planning, North Carolina State Highway and Public Works Commission, Raleigh, 1953. Tables I and II, pp. 6 and 9.

[3] See footnote 1, p. 17.

$71,014,000, were attributed to automobiles, and amounted to $1.63 per automobile when the amount is divided by the number of registered vehicles.

Carrier taxes

The prior discussion has outlined the major phases of assigning registration and associated fees. The assignment of the $64,036,000 in motor-carrier tax revenues was made by study of the individual reports of the States. This indicated that $7,268,000 might be assigned to buses and the remaining $56,768,000 assigned to trucks. Undoubtedly there are some instances of certain carrier taxes or public-service permit fees and related revenues that may be attributed to taxicabs but insufficient evidence was found of such payments to make any allocation. In any case, it is improbable that a substantial amount would be involved.

For the purpose of this study it was also assumed that carrier taxes can be assigned entirely to buses and to trucks of more than 12,000 pounds gross-vehicle-weight rating. Since the individual State records did not distinguish between the classes of vehicles upon which carrier taxes were levied, an arbitrary procedure was adopted in assigning them to the various groups. By taking the average amount of motor-carrier tax that would be paid by a vehicle of over 40,000 pounds as the quantity X, it was assumed, in computing carrier taxes, that vehicles in the 30,001–40,000-pound-group could be assigned a value of $0.75X$; trucks and combinations in the 24,001–30,000-pound-group, a value of $0.5X$; vehicles in the 20,001–24,000-pound-group, a value of $0.25X$; vehicles in the 16,001–20,000-pound-group, a value of $0.1X$; and vehicles in the 12,001–16,000-pound-group, a value of $0.05X$. The value of X was found to be $94.32. It might be said that this is systematic guessing, and there would be more than a grain of truth to it. Yet, in the absence of detailed basic data, any assignment of motor-carrier taxes to various groups of vehicles must necessarily be on an arbitrary basis and, regardless of the complexity of any formula adopted, it would be reasonably certain to contain many of the properties of the estimate made here.

Travel and Fuel-Tax Payments

Although much is known about the character and extent of motor-vehicle use, there is a present lack of complete information about the distribution of highway travel in rural and urban areas, especially that pertaining to the subdivision of this travel among the classes of vehicles for which it was desired to make estimates in this study. Nevertheless, such an estimate of travel during 1952, classified according to these vehicle types, had to be made if the fuel use and fuel-tax payments of the individual types of vehicles were to be calculated.

Motor-vehicle travel

Estimates of passenger-car, bus, and truck travel in the United States were issued by the Bureau for each of the years from 1936 through 1948.[4] The principal factors controlling the calculations made for 1936 were the traffic volumes, characteristics, and relations as determined from rural traffic counts, and from the motor-vehicle allocation and road-use studies conducted between 1935 and 1939, covering both rural and urban travel.

These projects were included in the program of basic highway planning studies undertaken jointly by the State highway departments and the Bureau of Public Roads. Estimates for the succeeding years were based upon the calculations made for 1936, such modifications being made as were necessary to reflect known trends in motor-vehicle registrations, fuel consumption, and vehicle use. The principal factors controlling the calculations for the individual years were the annual estimates of rural traffic made by the Bureau from traffic counts obtained by the State highway departments, the annual reports of the highway use of motor fuel made by State authorities, and reports of motor-vehicle registrations, also made by State authorities. Publication of these estimates was discontinued after 1948 because it was felt that some of the basic relations existing in 1936, and upon which the entire structure of the estimates was predicated, might have changed considerably. Since that time only estimates of rural travel have been published.

Basis of Travel Estimates

The same basic procedures employed in preparing the estimates for 1936–48 were used in developing the estimate of the total passenger-car, bus, and truck travel for 1952, presented in table 4. For purposes of this study, however, it was necessary to subdivide the estimate of total truck travel into the various visual classifications shown in the table. In rural areas, classification counts have been made regularly by the State highway departments as a part of the highway planning survey operations, and the percentage distribution shown by these counts was used in subdividing the total rural vehicle-mileage of trucks. In urban areas, comprehensive classification count data are not available. Two other sources of information are available from the planning survey operations conducted by the States, however, and these were used in subdividing the total urban vehicle-mileage of trucks. Estimates of travel by the various visual classifications of trucks were developed for the large cities from information collected in origin and destination traffic studies of the home-interview type, and for the smaller cities from information obtained in motor-vehicle-use studies.

In the home-interview origin and destination studies it is standard practice to collect data concerning the type of truck, the licensed gross weight, and the daily mileage traveled in the urban area as well as the origin and destination of each trip. Information is also available in these studies concerning the number, type, origin, and destination of all trucks entering and leaving urban areas. Twelve cities[5] were selected from those in which home-interview studies have been made and special tabulations of the urban travel by type of truck were made for these cities. Some of these tabulations were made by the State highway departments and some by the Bureau of Public Roads. Percentages and factors developed from these data were used in estimating the urban vehicle-mileage of trucks by visual types in the larger cities for the country as a whole.

The motor-vehicle-use studies are also home-interview studies designed to obtain on a Statewide basis much the same types of information as are obtained for a single city or urban area in the home-interview origin-and-

[4] See previous annual articles on traffic in PUBLIC ROADS: vol. 25, Nos. 3, 7, 12, and vol. 24, No. 10.

[5] Camden, Dallas, Duluth, Houston, Madison, Minneapolis, Philadelphia, Racine, St. Paul, Seattle, Superior, and Washington, D. C.

Table 4.—Estimated travel during 1952, classified by place of travel [1] and by vehicle type

Vehicle type	Vehicle-miles of travel in—			Distribution of travel		
	Rural areas	Urban areas	Total	Rural areas	Urban areas	Total
	Millions	*Millions*	*Millions*	*Percent*	*Percent*	*Percent*
Passenger cars	213,464	197,404	410,868	77.01	83.98	80.21
Buses:						
Commercial	1,444	1,750	3,194	.52	.74	.62
Other	1,026	114	1,140	.37	.05	.22
All buses	2,470	1,864	4,334	.89	.79	.84
Single-unit trucks:						
Panel and pickup	22,075	13,324	35,399	7.97	5.67	6.91
Other 2-axle, 4-tire	2,083	5,834	7,917	.75	2.48	1.55
All 2-axle, 4-tire trucks	24,158	19,158	43,316	8.72	8.15	8.46
2-axle, 6-tire	20,453	13,600	34,053	7.38	5.79	6.65
3-axle	1,557	388	1,945	.56	.16	.38
All single-unit trucks	46,168	33,146	79,314	16.66	14.10	15.49
Vehicle combinations:						
Tractor-semitrailer	14,013	2,465	16,478	5.06	1.05	3.22
Truck-trailer	1,061	187	1,248	.38	.08	.24
All combinations	15,074	2,652	17,726	5.44	1.13	3.46
All trucks and combinations	61,242	35,798	97,040	22.10	15.23	18.95
All vehicles	277,176	235,066	512,242	100.00	100.00	100.00

[1] Urban areas include all incorporated places and delimited urban compacts.

Table 5.—Estimated travel during 1952, classified by ownership of vehicle and by vehicle type

Vehicle type	Vehicle-miles of travel by—			Distribution of travel by—		
	Total	Government-owned vehicles	Private and commercial vehicles	Total	Government-owned vehicles	Private and commercial vehicles
	Millions	*Millions*	*Millions*	*Percent*	*Percent*	*Percent*
Passenger cars	410, 868	1, 597	409, 271	80. 21	25. 42	80. 89
Buses:						
Commercial	3, 194	-------	3, 194	. 62	------	. 63
Other	1, 140	770	370	. 22	12. 26	. 07
All buses	4, 334	770	3, 564	. 84	12. 26	. 70
Single-unit trucks:						
Panel and pickup	35, 399	1, 428	33, 971	6. 91	22. 73	6. 71
Other 2-axle, 4-tire	7, 917	319	7, 598	1. 55	5. 08	1. 50
All 2-axle, 4-tire trucks	43, 316	1, 747	41, 569	8. 46	27. 81	8. 21
2-axle, 6-tire	34, 053	1, 374	32, 679	6. 65	21. 87	6. 46
3-axle	1, 945	79	1, 866	. 38	1. 26	. 37
All single-unit trucks	79, 314	3, 200	76, 114	15. 49	50. 94	15. 04
Vehicle combinations:						
Tractor-semitrailer	16, 478	664	15, 814	3. 22	10. 57	3. 13
Truck-trailer	1, 248	51	1, 197	. 24	. 81	. 24
All combinations	17, 726	715	17, 011	3. 46	11. 38	3. 37
All trucks and combinations	97, 040	3, 915	93, 125	18. 95	62. 32	18. 41
All vehicles	512, 242	6, 282	505, 960	100. 00	100. 00	100. 00

destination studies. Because of their Statewide, rather than local emphasis, the sampling rates employed within cities in the motor-vehicle-use studies are much lower than those used in the origin-and-destination studies; therefore, the stability and reliability of the motor-vehicle-use samples are lower when only a single city or size-group of cities is considered. However, the data available from these studies could be used to good advantage in estimating the travel of various classes of trucks and combinations in the smaller-sized cities and villages as a whole. Data obtained in seven States, the only ones in which motor-vehicle-use studies have been completed up to the present, were used in making these estimates. In addition to the travel data applied, information obtained through these studies relative to the distributions of dwelling units, population, and motor vehicles was also used in refining the calculations.

Other sources of information used included estimates of travel by commercial and other buses reported by the industry,[6] and estimates of automobile use reported by the Automobile Manufacturers Association.[7]

Total motor-vehicle travel on all roads and streets during 1952 was calculated to be 512 billion vehicle-miles, of which 411 billion, about 80 percent, was estimated to have been performed by passenger cars, 79 billion, nearly 16 percent, by single-unit trucks, 18 billion, somewhat more than 3 percent, by tractor-semitrailer and truck-trailer combinations, and 4 billion, nearly 1 percent, by buses.

This tabulation includes the travel of publicly owned non-military vehicles. It was desired to limit the calculation of fuel consumption and fuel-tax payments to the classifications of private and commercial vehicles shown in table 3 and figure 5. Consequently, the travel of publicly owned vehicles had to be eliminated from the estimated travel of all vehicles shown in table 4.

Estimates of the travel and fuel consumption of Federal civilian vehicles were determined from statistics compiled by the United States Bureau of the Budget, while estimates of the travel and fuel consumption of motor vehicles owned by State, county, and other local government agencies were developed from reports made (of the numbers of such vehicles) by most of the State highway departments to the Bureau of Public Roads.

The travel of publicly owned vehicles was determined to be 6 billion vehicle-miles, of which the amounts contributed by the individual vehicle types were as shown in the second column of table 5. The total travel of private and commercial motor vehicles, after deduction of public-vehicle travel, was 506 billion vehicle-miles, of which 409 billion was performed by passenger cars, 76 billion by single-unit trucks, 17 billion by combinations of freight-carrying vehicles, and nearly 4 billion by buses. The percentage distribution of this travel by vehicle groups was practically the same as for the total travel of all public, private, and commercial vehicles. This distribution is shown in figure 6.

Vehicle Operating Characteristics

In order to estimate the fuel consumption and fuel-tax payments for the individual classes of vehicles used in this study, it was necessary to determine certain of their operating characteristics such as average gross weights, percentages of vehicles using fuel other than gasoline, and rates of fuel consumption.

Operating gross weights

The calculated average operating gross weights used in this study for each type of vehicle are shown in table 6 and figure 7. Different methods were employed in arriving at the weights adopted for the various classes of vehicles.

The average operating gross weight of passenger cars was determined by a complex method of calculation in which these vehicles were divided by makes roughly into four groups, according to the weight of the most popular four-door sedan of each make. An average operating road weight was calculated for each make by adding to the shipping weight of the four-door sedan an allowance to cover nonstandard equipment (such as radios and heaters), fuel, water, two passengers, and baggage. The allowances varied from 600 pounds in the case of the vehicles in the lightest group to 900 pounds in the case of the heaviest vehicles. It was assumed that vehicles of all weight groups would have the same average travel. The average operating

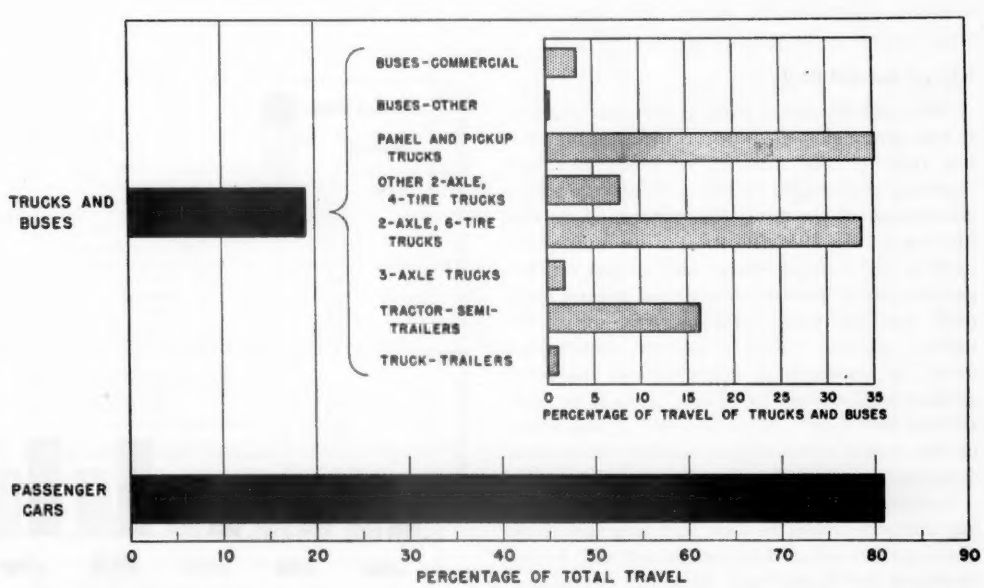

Figure 6.—Percentage distribution of travel by private and commercial vehicles in 1952.

[6] *Bus transportation*, vol. 32, No. 2, Feb. 1953, McGraw-Hill Publishing Co., New York, N. Y.

[7] *Automobile facts and figures*, 31st ed., 1951, Automobile Manufacturers Association, Detroit, Mich. See especially p. 48.

Table 6.—Operating chracteristics of various types of motor vehicles

Vehicle type	Average operating gross weight	Distribution of travel according to type of fuel used			Rates of fuel consumption by type of fuel used		
		Gasoline	Diesel	Other	Gasoline	Diesel	Other
	Pounds	*Percent*	*Percent*	*Percent*	*Gallons per mile*	*Gallons per mile*	*Gallons per mile*
Passenger cars	3, 965	100.0	(1)	(1)	0.06704	-------	-------
Buses:							
Commercial	23, 000	39.1	55.9	5.0	.26870	0.18590	0.26690
Other	11, 600	100.0	(1)	(1)	.12540	-------	-------
Single-unit trucks:							
Panel and pickup	4, 639	100.0	(1)	(1)	.07350	-------	-------
Other 2-axle, 4-tire	5, 834	100.0	(1)	(1)	.08420	-------	-------
2-axle, 6-tire	11, 684	100.0	(1)	(1)	.12590	-------	-------
3-axle	23, 611	100.0	(1)	(1)	.18980	-------	-------
Vehicle combinations:							
Tractor-semitrailer	35, 602	86.5	12.6	.9	.24120	.17230	.26800
Truck-trailer	46, 885	86.5	12.6	.9	.28320	.20230	.31470

[1] Percentage negligible.

gross weight for all passenger cars was calculated to be 3,965 pounds.

The operating characteristics of commercial buses differed so greatly from those of other types of buses that they were treated separately from the other types, such as privately owned buses operated by schools or institutions. The operating gross weight of 23,000 pounds assigned to commercial buses was determined by adding to the curb weight of a typical 42-passenger bus, such as is used in either city or suburban service, the weight of a load of 21 passengers. The operating gross weight of 11,600 pounds assigned to other buses represents the combination of the curb weight of a typical medium-sized school bus and the weight of an average load of 20 children.

The weights shown for the various classes of trucks and combinations are averages obtained from loadometer studies conducted in 1952 by the State highway departments. A total of 134,564 vehicles as found in the traffic stream on main rural roads were weighed. Some were empty, some overloaded, and some only partially loaded. The weights reported reflect these conditions. Since no data were available on weights of vehicles operating in cities, the rural road weights had to be applied to all traffic.

Use of special fuels

Although the use of fuels other than gasoline in the propulsion of motor vehicles is increasing rapidly, the amount of such so-called "special" fuels used is still a relatively small percentage of the total fuel consumed on the highways. In 1952 the total of all motor fuel used in the United States was 40,584 million gallons, while the total amount of special fuels used for highway purposes was only 805 million gallons. This relatively small segment of motor-fuel consumption assumes greater importance, however, when it is considered that nearly all of this fuel is consumed by the larger commercial vehicles—buses and combinations of freight-carrying vehicles.

Information reported by the commercial bus industry indicates that very large portions of its operations are now carried on with buses propelled by diesel fuel, liquefied petroleum gas, and other nongasoline fuels. The specific percentage relations used in this analysis are based upon reports from 24 intercity, intracity, and suburban operators.[8]

These data, which appear to be supported by other reliable information, indicate that more than 50 percent of the fuel now used in common-carrier buses is diesel fuel, while the use of liquefied petroleum gas has become an important factor in some instances. Although there is undoubtedly some use of these fuels in buses engaged in other types of operations, available information seems to indicate that such use is insignificant.

Nongasoline fuels are also used to some extent in single-unit trucks, but, inasmuch as the achievement of significant savings from the use of these fuels requires large-scale operations, such use is thought to be negligible and all of the consumption of these fuels in freight-carrying vehicles was assigned to combinations rather than single vehicles.

Fuel consumption rates

The rate at which a certain motor vehicle or combination of vehicles will consume fuel in its operations over the highways is affected at any given time by a number of factors, among which the following are of major importance: Type and grade of fuel used, characteristics of the engine, gear ratios, frequency of stops, condition of the vehicle, gradients encountered, types and conditions of roads traveled, weather, operating gross weight of vehicle (or combination) and contents, and driving techniques employed.

When the total of all motor vehicles in service, operating throughout the year under widely varying conditions, is being considered, and if only a broad and general analysis is undertaken as was the case in this instance, the effects of such factors as frequency of stops, topography, weather, condition of the vehicle, and driving techniques employed tend to become compensating and have little effect upon the determination of average rates of fuel consumption. Consequently, in the analysis undertaken for this study, no attempt was made to take any factor other than gross vehicle weight into account except in a very limited way, as is noted subsequently.

Figure 8 shows the compromise curve indicating the relation between gross weight and gasoline consumption that was plotted from the equation developed for this article, and the other fuel-consumption data that were considered in developing it. This equation is intended to indicate approximate gasoline-consumption rates for vehicles with gross weights up to at least 72,000 pounds, operating under average conditions.

This gasoline-consumption equation was not statistically developed in the ordinary sense. Rather, it is a composite of values for numerous gross-weight groups obtained from each of several previous determinations by other investigators. Since it was beyond the scope of this study to assemble original data on the fuel-consumption rates of motor vehicles, it was necessary to draw on the work of others. Although many sources of data were investigated, none was found which appeared to meet present needs in all respects. Some, like the determinations of the

[8] *Bus transportation*, vol. 32, No. 11, Nov. 1953, McGraw-Hill Publishing Co., New York, N. Y.

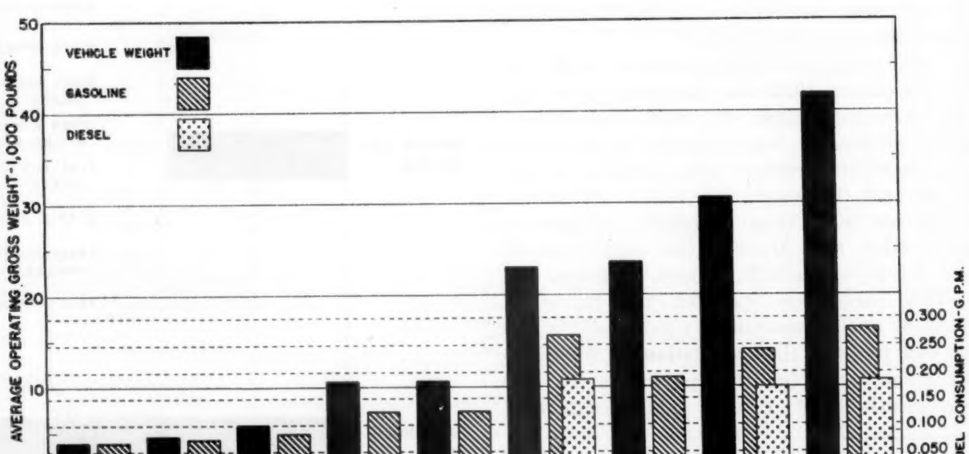

Figure 7.—Operating characteristics of various types of vehicles.

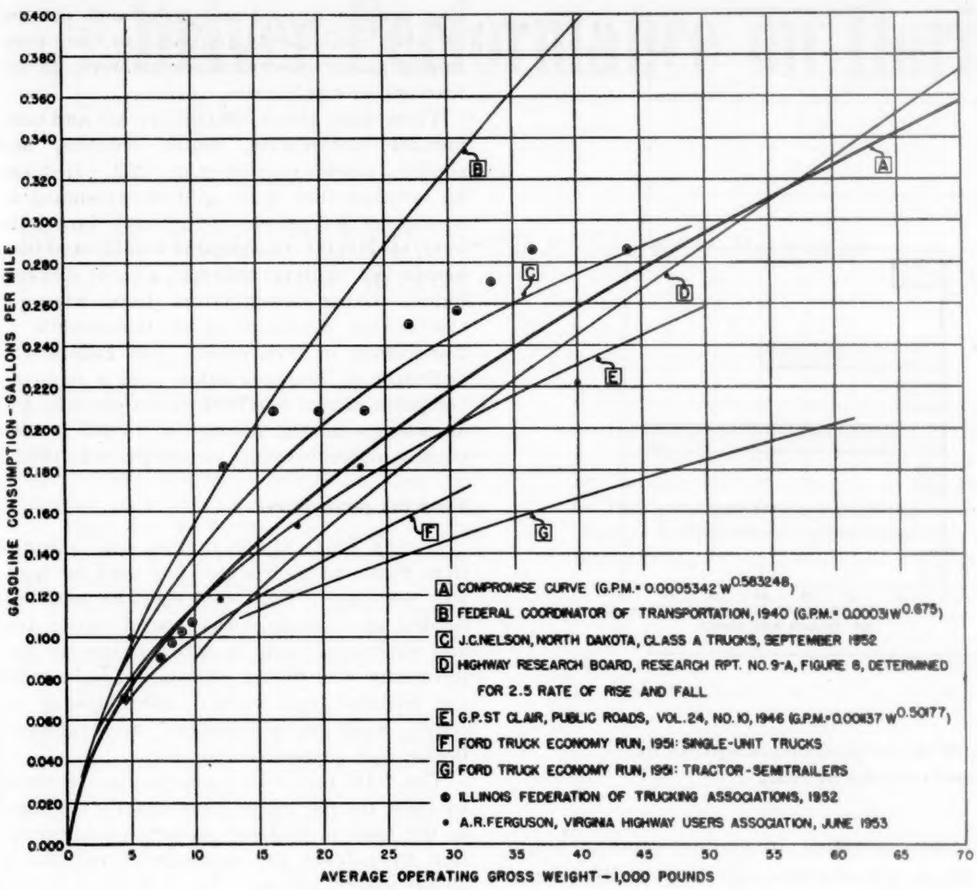

Figure 8.—Estimated fuel consumption of gasoline-powered vehicles compared with average operating gross weight.

calculated and plotted to logarithmic scales it was found that they fitted closely a straight line having the following equation:

$$G.P.M.=0.0005342W^{0.583248}$$

where $G.P.M.$=gallons per mile, and W= average operating gross weight of vehicle.

Consequently, it was decided that for purposes of the present analysis this fuel consumption equation could be applied throughout the entire range of gross weights for which gasoline consumption would need to be calculated.

As stated previously, this equation applies only to gasoline-powered vehicles. It is known that different rates of fuel consumption will apply to diesel-powered vehicles, but there are not sufficient data at hand to permit the calculation of an equation for them. After consultation with representatives of the trucking industry it was decided to assume that, for operating gross weights above 20,000 pounds, diesel vehicles will consume, on the average, about 30 percent less fuel than will gasoline-powered vehicles of equal weight. No special allowance was made for vehicles using other fuels, such as liquefied petroleum gas, partly because of their negligible importance in the nationwide picture, and partly because available data seemed to indicate that such vehicles generally have fuel-consumption rates closely approximating those of similar gasoline-powered vehicles.

All of the gasoline-consumption rates shown in table 6 and figure 7 were developed by applying the derived equation to the average operating gross weights shown except in the

Federal Coordinator of Transportation,[9] were developed from information that is now so old that is does not reflect conditions now known to prevail, especially in the higher gross-weight brackets. Others, like the fuel-consumption rates developed from the Ford data,[10] are based upon limited coverage of engines, vehicle types, or loadings, and so tend to give values, for certain weight ranges, that deviate rather widely from the consensus of findings.

After plotting all of this information as shown in figure 8, it became evident that a new curve, or set of curves, should be developed. Some students of the problem contend that a single fuel-consumption curve cannot be developed to fit all types of vehicles from passenger cars through the heaviest combinations. When the gasoline-consumption equation adopted for use in this study was developed, it had not been predetermined that a single curve could be applied to all gross weights. However, when average fuel-consumption rates for each of numerous values of operating gross weights, ranging from 3,000 to 50,000 pounds, had been

[9] *Public aids to transportation*, Federal Coordinator of Transportation, vol. IV, 1940. See especially pp. 141–43.

[10] *Mileage, gross vehicle weight, and fuel consumption of commercial vehicles*, presented by Robley Winfrey at 33d Annual Meeting of the Highway Research Board, Washington, D. C., Jan. 12, 1954.

Table 7.—Fuel consumption and tax payments in 1952, classified by various types of private and commercial motor vehicles

Vehicle type	Total miles traveled	Gasoline-powered vehicles		Diesel-powered vehicles		Vehicles powered by other fuels		Total fuel consumed		Total tax payments
		Mileage	Fuel consumed	Mileage	Fuel consumed	Mileage	Fuel consumed	Gallons	Distribution	
	Millions	*Millions*	*Million gallons*	*Millions*	*Million gallons*	*Millions*	*Million gallons*	*Millions*	*Percent*	*Million dollars*
Passenger cars	409,271	409,271	27,438	------	------	------	------	27,438	68.771	1,353.3
Buses:										
Commercial	3,194	1,249	336	1,785	332	160	43	711	1.782	35.0
Other	370	370	46	---	---	---	----	46	.115	2.3
All buses	3,564	1,619	382	1,785	332	160	43	757	1.897	37.3
Single-unit trucks:										
Panel and pickup	33,971	33,971	2,497	---	---	---	----	2,497	6.259	123.2
Other 2-axle, 4-tire	7,598	7,598	640	---	---	---	----	640	1.604	31.5
All 2-axle, 4-tire trucks	41,569	41,569	3,137	---	---	---	----	3,137	7.863	154.7
2-axle, 6-tire	32,679	32,679	4,114	---	---	---	----	4,114	10.311	202.9
3-axle	1,866	1,866	354	---	---	---	----	354	.887	17.5
All single-unit trucks	76,114	76,114	7,605	---	---	---	----	7,605	19.061	375.1
Vehicle combinations:										
Tractor-semitrailer	15,814	13,679	3,299	1,993	343	142	38	3,680	9.223	181.5
Truck-trailer	1,197	1,035	293	151	31	11	3	327	.820	16.1
All combinations	17,011	14,714	3,592	2,144	374	153	41	4,007	10.043	197.6
All trucks and combinations	93,125	90,828	11,197	2,144	374	153	41	11,612	29.104	572.7
All vehicles	505,960	501,718	39,017	3,929	706	313	84	39,807	99.772	1,963.3
Fuel consumed by motorcycles, etc	-----	-----	----	---	---	---	----	91	.228	4.5
Total fuel consumed and tax payments	-----	-----	----	---	---	---	----	39,898	100.000	1,967.8

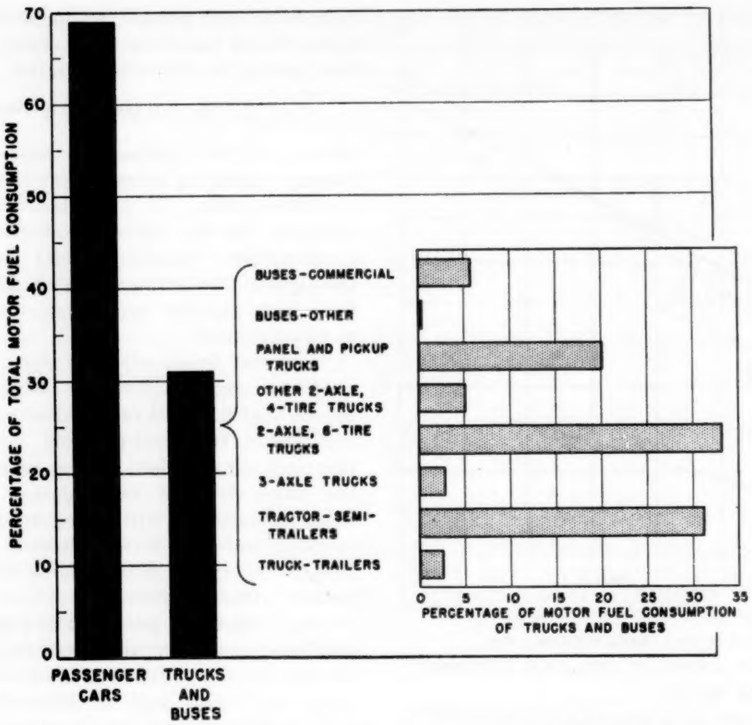

Figure 9.—Percentage distribution of motor-fuel consumption by private and commercial vehicles in 1952.

case of commercial buses. Available operating data indicate that relations between the gasoline-consumption rates and average operating weights of intercity buses are almost in line with the corresponding relations calculated by use of the equation, but that in the case of intracity and suburban buses the rates are much higher, probably because of the combined effects of frequent stops, urban congestion, and other factors peculiar to such operations. The composite gasoline-consumption rate shown was developed from operating statistics of the 24 companies previously cited.[11]

Fuel Consumption and Fuel-Tax Payments

Table 7 presents the calculated fuel consumption and fuel-tax payments of each of the various classes of vehicles indicated in the visual classification adopted for this study. Figure 9 shows the percentage distribution of indicated total fuel consumption.

Fuel consumption

The fuel-consumption data shown in table 7 were calculated by multiplying the total mileages traveled by the corresponding rates shown in table 6. Separate calculations of gasoline, diesel, and other fuel used were made on the basis of the percentages of total use there indicated.

The total calculated consumption of 39,807 millions of gallons of fuel of all kinds is 91 million gallons, or 0.225 percent, below the 39,898 million gallons of fuel used by private and commercial vehicles for highway purposes in 1952. However, the analysis made for this article did not take into account fuel consumed by motorcycles, motor scooters, and other similar vehicles, nor did it give consideration to the use of fuel on which highway-user taxes were paid and no refunds claimed for such nonhighway purposes as the operation of gasoline-powered lawnmowers, garden tractors, or small boats.

There were about 408,000 private and commercial motorcycles, motor scooters, and similar vehicles registered in 1952. If it can be assumed that these vehicles consumed an average of 200 gallons of fuel each during the year, their total consumption would have been nearly 82 million gallons, a not unlikely figure. Other investigators have averaged the annual consumption of motorcycles at 250 gallons, or even more. The Federal Coordinator of Transportation used a fuel-consumption rate of 0.027041 gallon per mile and an average annual mileage of 15,000 in estimating motorcycle fuel consumption in 1932.[12]

Fuel tax payments

During 1952, $1,968 million was collected from State taxes on motor fuel used for highway purposes. This total excludes taxes refunded upon nonhighway use of motor fuel and allowance made in a few States to taxpayers for cost of tax collection. It includes the incomes from certain miscellaneous receipts, such as distributors' and retailers' license fees, inspection fees, etc.

The total motor-fuel consumption covered by these tax payments is not exactly the same as the total of highway motor-fuel consumption by private and commercial vehicles of 39,898 million gallons. Tax collections do not indicate actual fuel consumption during a given year because of the time lag between payment of the fuel tax and the actual use of motor fuel and the handling of tax refunds for nonhighway use. Claims for nonhighway use in the fall of one year may not be paid until the following year.

For this reason it was decided not to attempt to calculate tax payments directly from the gallonage distribution shown in table 7. Instead, a percentage distribution was calculated from these data and applied to the total collections of $1,968 million, on the assumption that the percentages of use reflected by the collections would be essentially the same as those reflecting actual use during 1952. The results of this calculation are shown in the last column of table 7.

[11] See footnote 8, p. 24.

[12] See footnote 9, p. 25.

Driver Performance on Horizontal Curves

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Some important observations were derived from this study of free-moving passenger-car speeds on horizontal curves of two-lane rural highways. Drivers do not slacken speed after entering a curve, presumably making their adjustments on the approaches. Speeds in the shorter-radius inside lanes are no less than in the outside lanes, despite the fact that sight distances average 20 percent shorter. Operating speed and the degree of curvature are linearly related: while drivers do not move at the high speeds permissible by the design on easy curves, they often exceed the design speed on sharp curves.

Superelevation apparently has no effect on vehicle speeds, and the utilized coefficient of side friction is relatively small when the superelevation is high. However, there is a close relation between "unit superelevation"—the rise per foot of width per degree of curvature—and safe driving speed. Few vehicles exceed a safe speed on horizontal curves designed with a unit superelevation of more than 0.005 foot per foot of pavement per degree of curvature.

Where the minimum sight distance is 400 feet or more, drivers travel at speeds from which a stop can be made within the available sight distance, but where the sight distance is below 400 feet, drivers travel at speeds from which a stop can be made within the available sight distance only when the perception and reaction times are ignored. Speeds are considerably lower on horizontal curves than on vertical curves with the same minimum sight distances.

It is evident that if roads are to be built safely for the accommodation of actual driver behavior—and this seems logical—the design of horizontal curves on two-lane rural highways should take into account unit superelevation, and should provide a minimum sight distance of at least 400 feet, allowing for reasonable perception, reaction, and braking time. That an adequate margin of safety is needed is evidenced from the implication in the study results that driver speeds are more controlled by the obvious danger of running off the road, when negotiating a horizontal curve, than by the possible hazard of an unseen object where sight distance is limited on either horizontal or vertical curves. The physical stress of centrifugal force can actually be felt, while the sight-distance hazard can only be imagined.

EXISTING highways are conglomerations of varied geometric designs. Some sections are designed in accordance with the most modern standards, to accommodate large volumes of traffic at relatively high speeds, but these are by far in the minority. The greater part of our highway system is of two-lane design, often inadequate for the volume of traffic carried. In many locations the most common deficiency is insufficient sight distance for safe operation at desired speeds on vertical and horizontal curves.

The effect of vertical curves on driver behavior and vehicle speeds was discussed in a paper presented by B. A. Lefeve at the annual meeting of the Highway Research Board in January 1953.[1] The problem of horizontal curvatures and their effects on driver performance is presented in this report.

Study Procedure

Driver performance and passenger-car speeds were recorded on a number of horizontal curves with minimum sight distances ranging from 200 to 655 feet and with curvatures from 3 to 29 degrees. Study locations were confined to sections of two-lane highway on which it might be expected that driver performance would be affected by horizontal curvature, superelevation, or limitation of sight distance. In no case did the approach grade exceed 3 percent, and no section had a vertical curvature in combination with the horizontal curvature.

All locations were on rural highways removed from the influence of intersections and with a minimum of interference from roadside development. The study included only passenger cars and, to insure that they were not influenced by other vehicles traveling in the same direction, those following another vehicle within a time spacing of 6 seconds were excluded.

The study was conducted in two phases. The first phase was initiated in 1951 in cooperation with the New York State Department of Public Works and included studies of driver behavior on 15 horizontal curves. At these curves the speed of each vehicle observed was recorded at 100-foot intervals over a distance of 1,000 feet, starting 500 feet ahead of the centers of the curves and ending 500 feet beyond the centers. This included the entire lengths of the curves, since they were from 400 to 900 feet long. (Observations of vehicle speeds on the approaches, however, were not included in this study.) The data were obtained in such a manner that the variation in speed on each curve could be related to the variation in the sight distance on the curve. The results obtained by this phase of the study are discussed in the first part of this report.

To supplement the data obtained in New York, the second phase of the study made use of data from studies conducted at 20 locations in Maryland, Illinois, Minnesota, and South Carolina. This phase consisted of determining passenger-car speeds at one point on each curve—at the point of minimum sight distance. The data collected at these locations were combined with the New York data for the greater portion of this report. The data from each study site were analyzed separately for vehicles traveling in the inside lane of the curve and for vehicles traveling in the outside lane of the curve.

It should be understood, of course, that the curves studied are on two-lane highways, and the "inside" lane is that side of the road nearest the center of the circle of which the curve is an arc; the "outside" lane, carrying traffic in the opposite direction, is the other half of the road.

The inside lane of a curve has a slightly sharper curvature and shorter radius than the outside lane. This difference should be kept in mind in the consideration of the results because the curvatures as reported are those as measured to the centerline of the pavement. Sight-distance measurements were made separately for each direction of travel, at the center of the lane, from a height of 4½ feet to an object 4 inches high in the same lane.

The speeds of approximately 125 free-moving passenger cars (not meeting another vehicle and more than 6 seconds behind the preceding vehicle) were observed at each study site. Satisfactory data were obtained for the inside lanes of 35 different curves and for the outside lanes of 33 of these curves, involving

[1] *Speed characteristics on vertical curves*, by B. A. Lefeve. Highway Research Board Proceedings, 1953, vol. 32, p. 395.

Table 1.—Locations studied and observed speed data on horizontal curves on two-lane highways

Location		Physical features			Inside lane of curve				Outside lane of curve			
					Minimum sight distance	Speed at minimum sight distance			Minimum sight distance	Speed at minimum sight distance		
State	Site No.	Pavement width [1]	Curvature	Superelevation		Average	90-percentile	95-percentile		Average	90-percentile	95-percentile
		Feet		*Ft./ft.*	*Feet*	*M.p.h.*	*M.p.h.*	*M.p.h.*	*Feet*	*M.p.h.*	*M.p.h.*	*M.p.h.*
Ill.	1	18	25° 00′	0.083	200	23.7	28.9	29.4	300	22.6	28.5	29.4
N. Y.[2]	2-*I*	22	17° 30′	.062	215	36.5	44.0	45.0	---	----	----	----
N. Y.[2]	2-*O*	22	4° 45′	.062	---	----	----	----	220	38.0	43.0	46.5
Md.	3	[3] 26	23° 50′	.077	215	31.5	36.2	38.1	455	32.2	36.2	37.8
N. Y.	4	17	20° 30′	.083	220	28.0	34.5	36.0	220	30.0	35.0	37.2
Md.	5	[3] 28	6° 52′	.036	236	38.6	46.3	47.6	452	36.9	42.1	43.9
Md.	6	24	9° 10′	.042	256	41.4	47.5	49.1	453	40.7	47.1	49.5
Md.	7	[4] 22	12° 15′	.045	285	35.7	41.5	42.9	391	35.2	40.4	42.9
Md.	8	22	13° 44′	.068	297	40.4	49.7	52.9	323	41.2	46.9	48.6
Minn.[5]	9	26	29° 00′	.062	300	25.1	29.7	31.5	---	----	----	----
N. Y.	10	24	10° 00′	.073	300	35.5	44.0	46.4	325	37.5	44.5	45.5
Md.	11	24	3° 50′	.014	303	46.6	55.1	58.5	526	46.3	53.0	55.5
Md.	12	24	4° 35′	.028	303	40.8	46.5	49.0	489	42.4	47.2	50.4
Md.	13	[3] 26	10° 18′	.038	308	41.9	46.3	47.1	377	37.0	44.2	46.5
N. Y.	14	23	9° 30′	.073	320	37.8	45.0	47.6	320	37.0	44.2	46.3
N. Y.	15	22	11° 00′	.073	320	36.0	45.0	46.8	340	35.0	42.0	43.8
Md.	16	24	8° 02′	0	324	44.3	52.0	53.7	452	40.3	47.0	49.3
Md.	17	24	6° 52′	.042	342	41.6	46.8	49.1	439	40.4	48.2	50.9
N. Y.	18	23	7° 00′	.052	350	41.5	49.5	52.2	375	42.0	47.5	53.9
S. C.	19	18	3° 00′	.030	360	40.9	53.1	59.0	360	34.9	44.7	47.9
Md.	20	[3] 26	7° 40′	.064	371	40.6	46.7	48.9	655	46.3	53.0	56.0
Md.	21	24	4° 35′	.021	377	51.7	58.3	60.2	546	46.9	52.5	53.7
N. Y.	22	24	11° 30′	.080	380	40.5	49.5	52.4	380	39.0	48.0	49.3
N. Y.	23	24	6° 30′	.062	400	42.5	50.5	53.4	400	41.5	51.0	53.7
Md.	24	20	5° 40′	.033	407	43.5	49.4	52.4	550	46.0	52.9	56.2
Minn.[5]	25	19	7° 30′	.062	420	39.2	48.7	50.6	---	----	----	----
N. Y.	26	22	5° 30′	.042	435	37.5	46.5	48.3	460	38.0	47.5	49.9
N. Y.	27	20	6° 00′	.062	440	42.5	55.0	57.3	440	40.0	50.0	50.6
Md.	28	24	4° 35′	.049	450	45.0	52.5	58.5	557	45.5	52.0	53.0
N. Y.[2]	29-*I*	20	4° 00′	.052	460	45.0	55.0	58.9	---	----	----	----
N. Y.[2]	29-*O*	20	2° 45′	.052	---	----	----	----	460	48.0	58.0	60.9
Md.	30	24	5° 40′	.069	469	43.9	49.7	52.1	316	41.5	47.4	49.7
N. Y.	31	20	5° 30′	.042	470	41.0	51.8	53.8	430	40.5	49.0	51.0
N. Y.	32	20	4° 00′	.042	490	39.5	49.5	57.0	500	39.0	49.5	53.1
N. Y.	33	24	3° 30′	.040	500	45.5	54.0	56.4	530	45.0	56.0	58.7
S. C.	34	22	4° 00′	.060	500	40.2	48.7	50.6	500	43.0	52.0	54.9
N. Y.	35	22	4° 30′	.062	510	43.5	53.0	54.6	520	43.0	54.0	57.2

[1] Approach pavement same width as curve except as noted.
[2] Sites 2 and 29 were compound curves, so the curvature of the inside lane differs from that of the outside lane.
[3] Approach pavement 24 feet wide.
[4] Approach pavement 20 feet wide.
[5] At sites 9 and 25 data were not obtained for the outside lane.

8,400 vehicles. Table 1 contains a general description of each location and the observed speed data at the point of minimum sight distance.

Summary of Findings

The analyses of the data included investigations of the coefficient of side friction that vehicles actually develop in traversing horizontal curves, the effect of superelevation on driver behavior, sight distance as related to curvature, speed as related to sight distance and curvature, and actual passenger-car speeds as compared to various standards for safe speeds as based on stopping distances.

The data indicate the following for the conditions of speed and sight distance generally prevailing in the areas where the studies were conducted:

1. Drivers of free-moving passenger cars do not change their speeds appreciably after entering a horizontal curve. Any adjustment in speed that is made because of curvature or limited sight distance is made on the approach to the curve. Observations of vehicle speeds on the approaches were not included in this study.

2. Speeds in the outside lanes were about the same as those in the inside lanes despite the fact that minimum sight distances were, on an average, 20 percent greater in the outside lanes than in the inside lanes of the curves included in these studies Operating conditions as far as the minimum sight distance is concerned were therefore more critical for the inside lanes than for outside lanes, especially on the sharper curves.

3. The amount of superelevation on the curves studied had no effect on vehicle speeds. For this reason the utilized coefficient of side friction on the same degree of curvature is smaller when the superelevation is high than when it is low. Ten percent of the drivers develop a coefficient of side friction of 0.3 or more on horizontal curves sharper than 15 degrees. A coefficient of side friction of 0.16, however, is rarely exceeded on curves of 6 degrees or less.

4. Superelevation, as normally used in terms of feet of rise per foot of pavement width, without regard to the sharpness of the curve, bears no relation to the percentage of vehicles exceeding the "safe" speed based on curvature, superelevation, and coefficient of side friction. A close correlation exists, however, between *unit superelevation* and the percentage of vehicles exceeding the computed safe speed based on curvature and superelevation; the "unit superelevation" being the feet of rise per foot of width per degree of curvature. The analysis indicates that few vehicles exceed a safe speed on horizontal curves designed with a unit superelevation of more than 0.005 foot per foot of width per degree of curvature. This is a very simple unit to apply in the design of horizontal curves.

5. The minimum sight distance on horizontal curves is not necessarily controlled by or related to the degree of curvature. On the curves studied, however, there was a general tendency for the flatter curves (those of longer radii) to have the longer minimum sight distances.

6. Operating speed and degree of curvature are closely related, and the relation is linear. Drivers do not drive at the high speed permitted by the design on easy curves, and exceed the design speed on sharp curves sometimes by as much as 10 miles per hour.

7. Considering curvature and sight distance only, curvature has a much greater effect on vehicle speed than sight distance.

8. Driver performance on horizontal curves is such that when the minimum sight distance is 400 feet or longer, few drivers exceed what can be considered a safe speed regardless of which of the commonly employed factors is used in computing driver stopping distances. With the shorter sight distances, however, most drivers stay within a speed from which they could come to a stop within the available sight distance only if no allowance is made for perception and reaction time. Between these two extremes the percentage of vehicles exceeding the safe speed depends on the criterion used to determine the safe speed.

From these studies it appears that sight distances should be at least 400 feet (if measured from a height of 4½ feet to 4 inches) on horizontal curves on two-lane main rural highways if drivers are to be expected to stop when an object suddenly appears in their lane.

9. Vehicle speeds are considerably lower on horizontal curves than on vertical curves with the same minimum sight distance.

New York Studies

In the New York studies, vehicle speeds were recorded in each of the two lanes at 100-foot intervals for a distance of 1,000 feet including the sharpest sections of the horizontal curves. The individual car speeds were obtained by measuring the time it took vehicles to travel the 100-foot distances between the stations on each curve. A distribution of vehicle speed and the average speed were thus obtained for vehicles while in each of the ten 100-foot sections. Using sight distances recorded separately for each direction of travel, the design speed based on the American Association of State Highway Officials standards for nonpassing sight distances only was determined for each curve in each direction. The percentage of cars exceeding the design speed determined in this manner at each 100-foot station was then obtained from the speed distribution.

Typical data recorded in New York are plotted for one location in the chart at the left in figure 1. The bottom portion of the chart shows the sight distances on the curve for

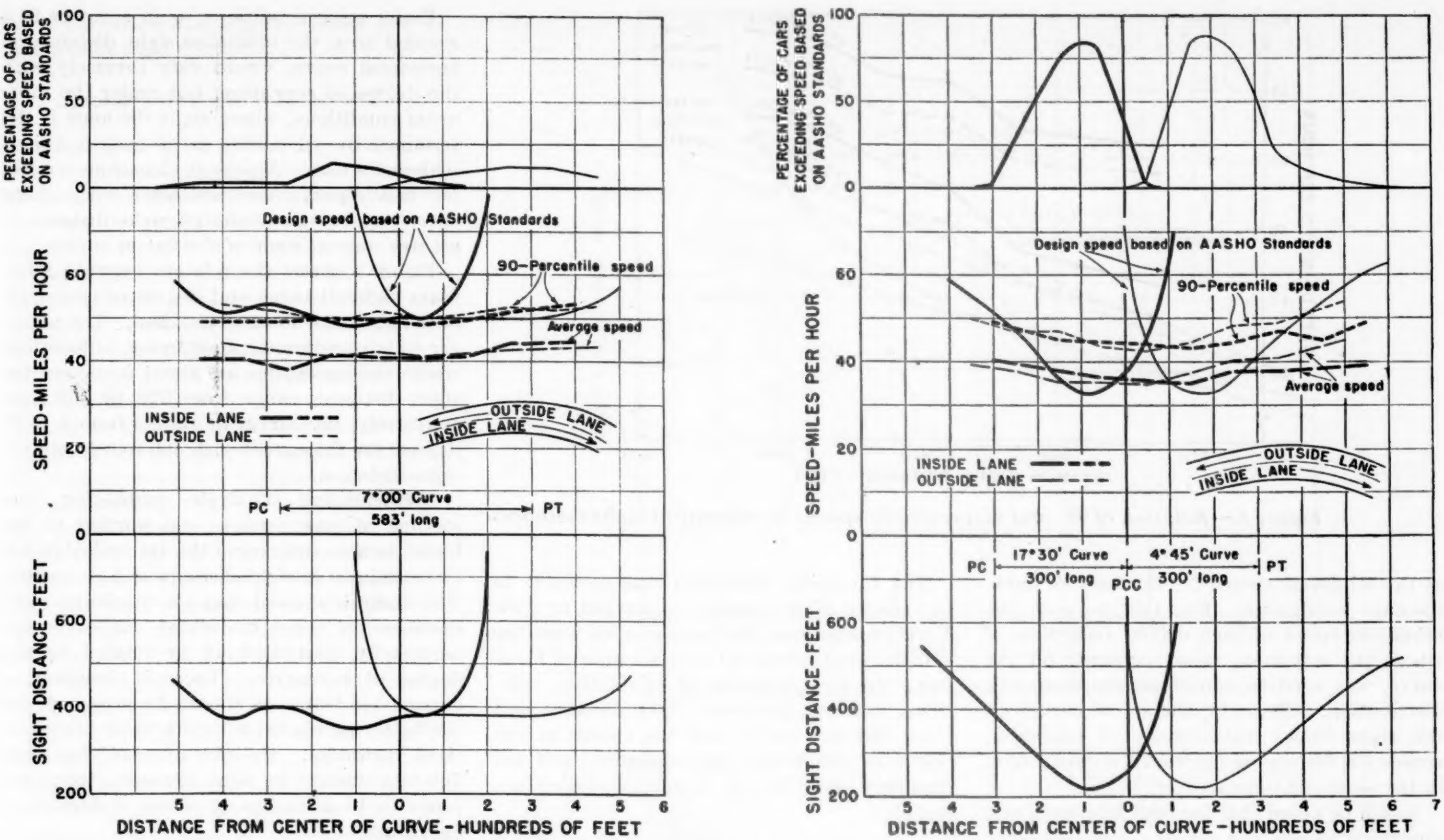

Figure 1.—Typical data recorded at two locations in New York State.

each direction of travel. The middle portion shows the average speeds, the 90-percentile speeds, and the design speeds based on A.A.S.H.O. nonpassing sight-distance standards. (The 90-percentile speed is that speed exceeded by only 10 percent of the vehicles.) As indicated, this was a 7° 00′ curve, 583 feet long. The upper portion of the chart shows the percentage of vehicles exceeding the design speed at the several points on the curve.

The minimum sight distance for each direction of travel occurs about 100 feet ahead of the center of the curve, and this is characteristic of all the horizontal curves studied. It will be noted that for the inside lane, where the minimum sight distance is 350 feet, the average and the 90-percentile free-moving passenger-car speeds were 41 and 50 miles per hour, respectively.

The chart at the right in figure 1 is for a location where the minimum sight distance was only about 200 feet. The two charts illustrate an important driver characteristic observed at all of the locations in New York—drivers of free-moving passenger cars do not change their speeds appreciably after entering a horizontal curve, even when the curvature is as sharp as 15 degrees. Most of the adjustment in speed that is made, whether because of curvature, limited sight distance, or other reasons, is made on the approach to the curve. (Observations of changes in speed on the approaches were not included in this study.) Furthermore, a rather high percentage of drivers travel around curves with short sight distances at speeds which are higher than those based on the A.A.S.H.O. design standards for nonpassing sight distance.

Even though drivers do not materially reduce their speeds while on a curve, there is a definite relation between operating speeds and the minimum sight distances on different curves in New York. Figure 2 shows two sets of speed distributions for horizontal curves having minimum sight distances between 200 and 550 feet, by 50-foot increments. (No locations were studied where the minimum sight distance was between 250 and 299 feet.) The curves on the left show the distributions

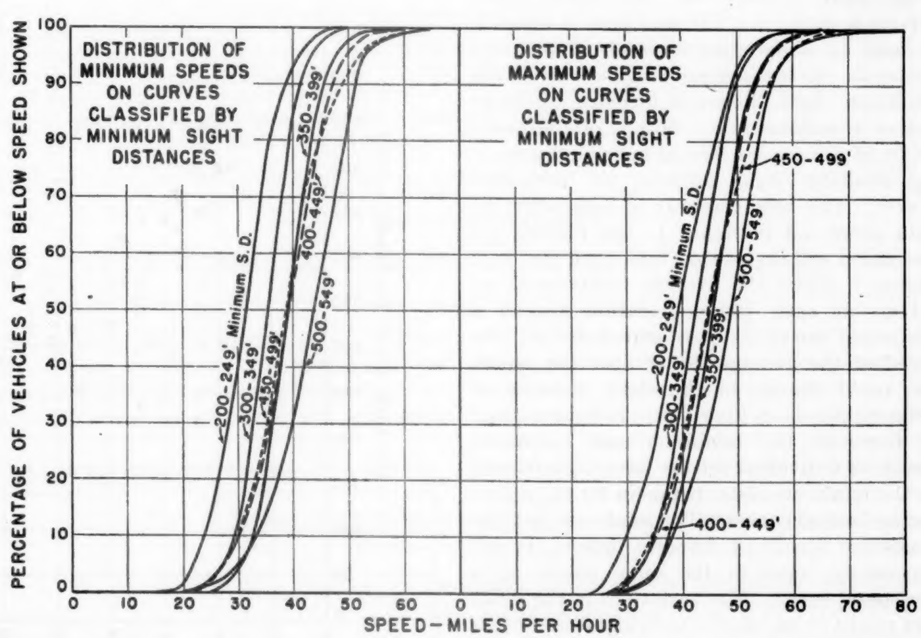

Figure 2.—Distribution of free-moving passenger-car speeds on horizontal curves of two-lane highways in New York State.

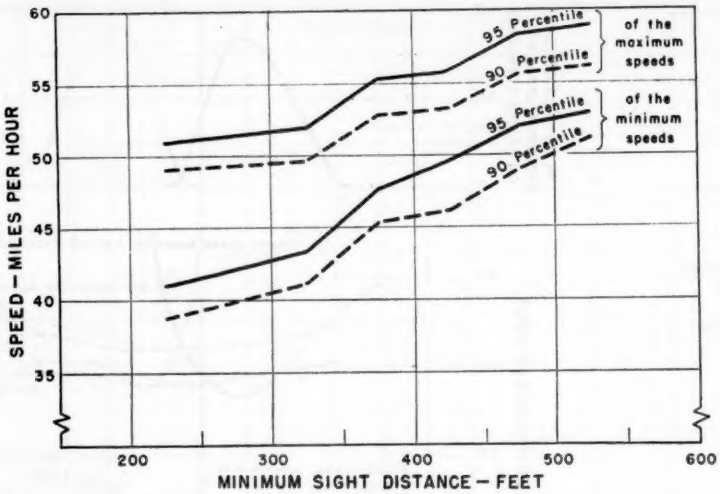

Figure 3.—Relation of 90- and 95-percentile speeds to minimum sight distance.

of the minimum speeds for the various sight-distance conditions. For this purpose the minimum speed of each driver, regardless of where the minimum speed occurred on the curve, was used to determine the frequency distribution. Similarly, the set of curves on the right shows distributions of maximum speeds for the several horizontal curves falling in the same sight-distance groupings.

It will be noted that for both minimum and maximum speeds, the speeds are considerably lower at locations where the minimum sight distance is below 250 feet than at locations where the minimum sight distance is greater than 500 feet. There is little difference between the speed distributions for the three minimum-sight-distance groups that range from 350 to 500 feet. There is a consistent relation between the speeds of the faster drivers (90-percentile speed or higher) and the minimum sight distance.

This relation between the speed and minimum sight distance for the higher speed drivers is shown in a different form in figure 3. It may be noted that for each of the four curves the speeds increase progressively as the minimum sight distances increase, although not at a uniform rate. Speeds of the faster group of drivers are related in some degree to the available sight distance on horizontal curves. This might appear to contradict the data presented in figure 1, but further examination will reveal that this is not the case. Figure 1 shows the average behavior of all drivers at each 100-foot station around a horizontal curve and, as stated before, the speed of the average driver does not reflect the rapid change in the sight distance at different points on the curve. In figures 2 and 3, however, the minimum and maximum speeds of individual drivers have been related to the minimum sight distances for the different horizontal curves. The minimum and the maximum speeds of different drivers do not necessarily occur at the same points on a horizontal curve. The variations in the make and model of car, in the individual perception and reaction times and other driver characteristics, undoubtedly affect the individual reactions to highway conditions.

The foregoing discussion was confined to the results of the studies conducted in New York because only in these studies were the vehicle speeds observed over a length of highway. In the remainder of this article, relations between speed and sight distance and other factors involve only the speeds at the points of minimum sight distance, and accordingly data for all locations studied are included.

Sight Distance–Curvature Relation

Drivers approaching horizontal curves can see that the sight distances are shorter on some curves than on others, and to some extent they can judge that one curve is sharper than another. Undoubtedly, drivers control their speed on the basis of their experience with respect to one or both of these factors.

Under some conditions, as in a cut or in a wooded area, the minimum sight distance on horizontal curves would vary inversely with the degree of curvature, but under the more usual conditions, where sight distance is determined by other than cross section, this is seldom the case. Among the locations studied for this report there are some very sharp curves where the minimum sight distance is greater than at some of the flatter curves.

Figure 4 shows the relation between minimum sight distance and degree of curvature as found on the 35 curves studied. The points are widely scattered. In extreme, at locations where the curvatures are about 5 degrees the sight distances range from 220 to 560 feet; conversely, the curvature ranges from 4 to 29 degrees for the curves with 300-foot minimum sight distance.

Mathematical analysis employing the method of least squares was applied to the basic data to determine the interrelation between minimum sight distance and curvature. The analysis showed that the minimum sight distance on these horizontal curves is not necessarily controlled by or related to the degree of curvature. There is, however, a general tendency, as should be expected, for the flatter curves to have the greater minimum sight distances. On the average, for each 100-foot change in sight distance, there appears to be a change of about 3 degrees in curvature.

Even though, in open and level terrain, the available sight distance is not necessarily related to the curvature, the design of highway curvature and superelevation is based on the probable future speeds and an effort is made to provide adequate sight distance for safe operation at those speeds. It is important, therefore, to determine to what extent drivers are influenced in their speeds by the combina-

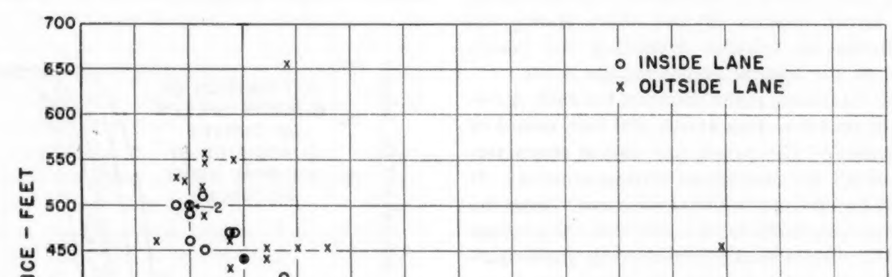

Figure 4.—Relation between minimum sight distance and curvature.

tion of curvature and superelevation and by the available sight distances.

Speed–Curvature Relation

The speeds at which drivers operated on the curves of various degrees are shown in figure 5. The points for these curves were plotted by combining the inside and outside lane speed data shown in table 3. For this purpose it was found not to be necessary to plot the lane speeds separately because for the same curve the average difference was only 0.2 mile per hour. (The arrangement within groups in table 3 was governed by considerations which will be explained later.)

Points are shown only for the average speed for each of the curvature groups in the table. The point shown for a curvature of 16 to 20 degrees represents only 1 location, but all the other points represent data averaged for 7 to 20 locations. The points for the 90- and 95-percentile curves are not shown, but they fell as close to their respective curves as those for the average speeds. Points representing speeds at the individual locations as well as those for the groups also came remarkably close to the curves.

The method of least squares was used to fit a straight line, a hyperbola, and a parabola to the data for the individual locations, and the straight-line relation between speed and curvature was found to give the best fit. The resulting equations, with the corresponding standard errors and coefficients of correlations, are shown in table 2. The high coefficients of correlation found for these equations indicate that operating speeds are very closely related to the degree of curvature for the range between 2-degree and 30-degree curves included in this study. The average speed is lowered by 3 miles per hour for each 4 degrees that the curvature increases, and the 95-percentile speed is lowered by 1 mile per hour for each 1-degree increase in curvature.

Included in figure 5 is a curve showing speeds that are presumed to be safe for the various degrees of curvature. These "safe" speeds are based on the average superelevation for each of the curvature groups in table 3 and the current standards of highway design [2] as shown in figure 6. This is a curved relation between speed and curvature, whereas the actual performance of drivers is a straight-line relation. A driver traveling at the average speed of all free-moving vehicles does not exceed what is considered a safe speed on any of the curves. The fastest 10 percent of the drivers, however, do exceed the safe speeds on

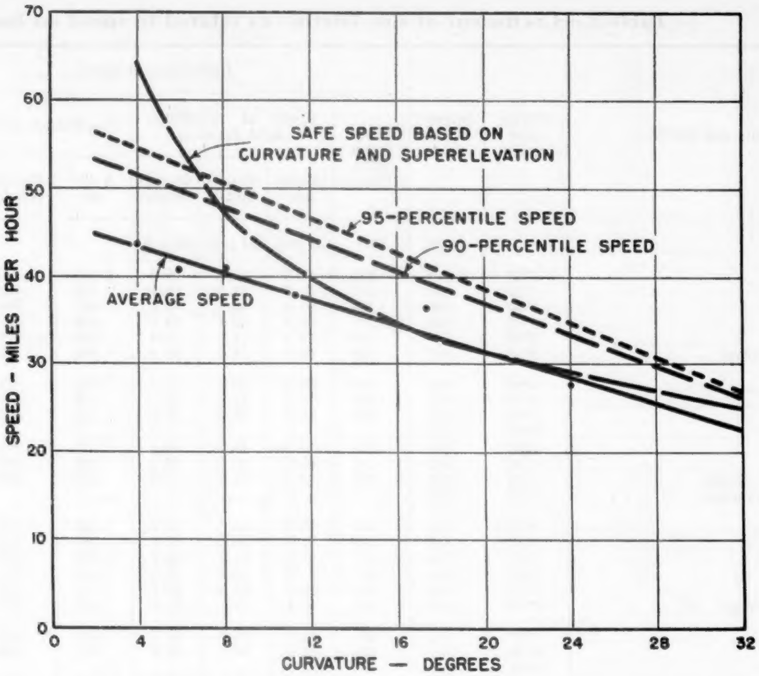

Figure 5.—Relation between speed and horizontal curvature.

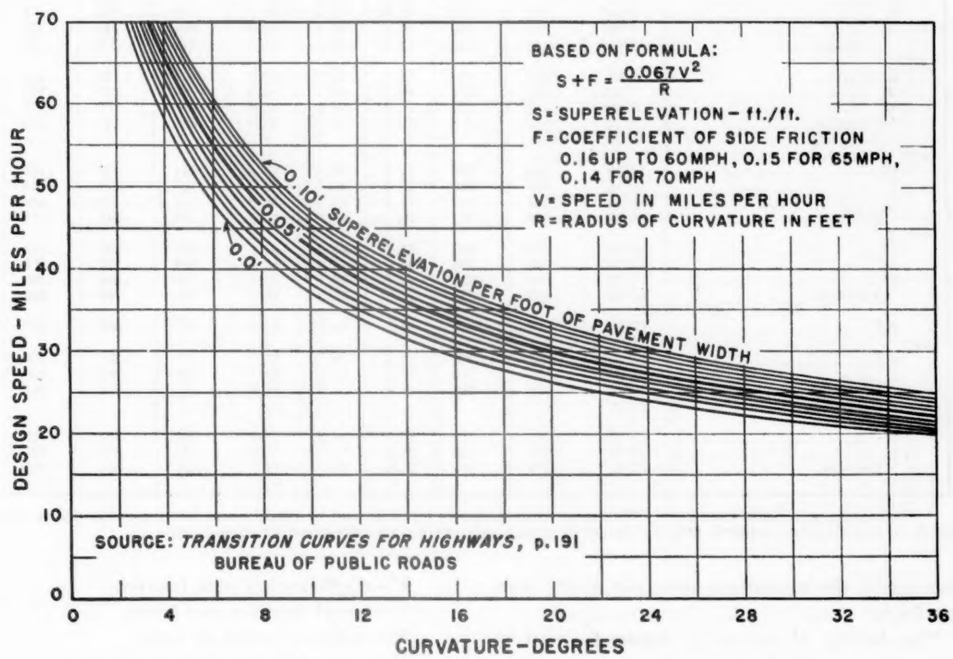

Figure 6.—Maximum curvature for various assumed design speeds.

curves sharper than 8 degrees, and on curves sharper than 16 degrees the average driver travels at about the safe speed, indicating that nearly half of the drivers exceed the safe speed. At individual locations included in this study, 10 percent of the drivers exceeded the safe speed by as much as 10 miles per hour. It is apparent, therefore, that when the road is clear and dry many drivers actually utilize a coefficient of side friction which exceeds that intended in modern highway design. Normally a low value of side friction is purposely used in design to provide some margin of safety. To reduce the needed side friction, highway designers make use of superelevation. Generally, however, the superelevation is limited to a maximum of 0.10 foot per foot, and even on the sharpest curves included in

[2] *Transition curves for highways*, by Joseph Barnett. Bureau of Public Roads, 1940. p. 191.

Table 2.—Relation between speed and horizontal curvature

Speed	Equation [1]	Standard error (adjusted)	Coefficient of correlation (adjusted)
		M.p.h.	
Average	$V_a=46.26-0.746\ D$	3.15	0.819
90-percentile	$V_{90}=55.22-0.909\ D$	3.29	.858
95-percentile	$V_{95}=58.46-1.000\ D$	3.51	.863

[1] V=speed in miles per hour; D=curvature in degrees.

Table 3.—Coefficient of side friction as related to speed on horizontal curves on two-lane highways

Group and site No.[1]	Curvature group	Superelevation	Inside lane of curve: Minimum sight distance	Inside lane: Speed at minimum sight distance: Average	Inside lane: Speed: 90-percentile	Inside lane: Speed: 95-percentile	Inside lane: Coefficient of side friction: Average	Inside lane: Coefficient: 90-percentile	Inside lane: Coefficient: 95-percentile	Outside lane of curve: Minimum sight distance	Outside lane: Speed at minimum sight distance: Average	Outside lane: Speed: 90-percentile	Outside lane: Speed: 95-percentile	Outside lane: Coefficient of side friction: Average	Outside lane: Coefficient: 90-percentile	Outside lane: Coefficient: 95-percentile
1A:		*Ft./ft.*	*Feet*	*M.p.h.*	*M.p.h.*	*M.p.h.*				*Feet*	*M.p.h.*	*M.p.h.*	*M.p.h.*			
11	3°50′	0.014	303	46.6	55.1	58.5	0.083	0.122	0.139	526	46.3	53.0	55.5	0.082	0.112	0.124
21	4°35′	.021	377	51.7	58.3	60.2	.122	.161	.173	546	46.9	52.5	53.7	.097	.127	.133
12	4°35′	.028	303	40.8	46.5	49.0	.061	.088	.101	489	42.4	47.2	50.4	.068	.091	.108
19	3°00′	.030	360	40.9	53.1	59.0	.029	.069	.092	360	34.9	44.7	47.9	.013	.040	.050
33	3°30′	.040	500	45.5	54.0	56.4	.043	.077	.088	530	45.0	56.0	58.7	.041	.086	.099
Average	3°54′	.027	369	45.1	53.4	56.6	.066	.103	.119	490	43.1	50.7	53.2	.058	.090	.102
1B:																
32	4°00′	.042	490	39.5	49.5	57.0	.031	.073	.110	500	39.0	49.5	53.1	.029	.073	.090
28	4°35′	.049	450	45.0	52.5	58.5	.059	.099	.134	557	45.5	52.0	53.0	.062	.096	.101
29-*I*	4°00′	.052	460	45.0	55.0	58.9	.043	.090	.110	-----	----	----	----	-----	-----	-----
29-*O*	2°45′	.052	-----	----	----	----	-----	-----	-----	460	48.0	58.0	60.9	.022	.056	.067
34	4°00′	.060	500	40.2	48.7	50.6	.016	.051	.060	500	43.0	52.0	54.9	.016	.066	.081
35	4°30′	.062	510	43.5	53.0	54.6	.038	.086	.095	520	43.0	54.0	57.2	.035	.091	.110
I-Average	4°13′	.053	482	42.6	51.7	55.9	.037	.079	.101	-----	----	----	----	-----	-----	-----
O-average	3°58′	.053	-----	----	----	----	-----	-----	-----	507	43.7	53.1	55.8	.036	.078	.091
2A:																
24	5°40′	.033	407	43.5	49.4	52.4	.093	.129	.149	550	46.0	52.9	56.2	.107	.153	.177
5	6°52′	.036	236	38.6	46.3	47.6	.084	.136	.146	452	36.9	42.1	43.9	.073	.106	.119
31	5°30′	.042	470	41.0	51.8	53.8	.066	.130	.144	430	40.5	49.0	51.0	.063	.112	.125
26	5°30′	.042	435	37.5	46.5	48.3	.048	.097	.108	460	38.0	47.5	49.9	.051	.103	.118
17	6°52′	.042	342	41.6	46.8	49.1	.097	.134	.152	439	40.4	48.2	50.9	.089	.114	.166
Average	6°05′	.039	378	40.4	48.1	50.2	.077	.125	.140	466	40.4	47.9	50.4	.077	.124	.141
2B:																
27	6°00′	.062	440	42.5	55.0	57.3	.065	.150	.168	440	40.0	50.0	50.6	.050	.113	.118
23	6°30′	.062	400	42.5	50.5	53.4	.075	.132	.155	400	41.5	51.0	53.7	.069	.136	.157
2-*O*	4°45′	.062	-----	----	----	----	-----	-----	-----	220	38.0	43.0	46.5	.018	.041	.058
30	5°40′	.069	469	43.9	49.7	52.1	.059	.095	.111	316	41.5	47.4	49.7	.045	.080	.095
I-average	6°03′	.064	436	43.0	51.7	54.3	.067	.125	.145	-----	----	----	----	-----	-----	-----
O-average	5°35′	.063	-----	----	----	----	-----	-----	-----	344	40.2	47.8	50.1	.042	.086	.101
3A:																
16	8°02′	0	324	44.3	52.0	53.7	.184	.254	.271	452	40.3	47.0	49.3	.153	.208	.228
6	9°10′	.042	256	41.4	47.5	49.1	.141	.200	.216	453	40.7	47.1	49.5	.136	.196	.221
18	7°00′	.052	350	41.5	49.5	52.2	.089	.149	.171	375	42.0	47.5	53.9	.092	.133	.186
Average	8°04′	.031	310	42.4	49.7	51.7	.139	.202	.221	427	41.0	47.2	50.9	.128	.179	.213
3B:																
25-*I*	7°30′	.062	420	39.2	48.7	50.6	.072	.146	.162	-----	----	----	----	-----	-----	-----
20	7°40′	.064	371	40.6	46.7	48.9	.084	.132	.150	655	46.3	53.0	56.0	.128	.188	.217
14	9°30′	.073	320	37.8	45.0	47.6	.086	.152	.179	320	37.0	44.2	46.3	.079	.144	.165
I-average	8°13′	.066	370	39.2	46.8	49.0	.081	.144	.165	-----	----	----	----	-----	-----	-----
O-average	8°35′	.068	-----	----	----	----	-----	-----	-----	487	41.6	48.6	51.2	.106	.169	.195
4A:																
13	10°18′	.038	308	41.9	46.3	47.1	.174	.220	.229	377	37.0	44.2	46.5	.127	.197	.222
7	12°15′	.045	285	35.7	41.5	42.9	.137	.201	.218	391	35.2	40.4	42.9	.132	.189	.218
8	13°44′	.068	297	40.4	49.7	52.9	.194	.329	.381	323	41.2	46.9	48.6	.205	.285	.311
Average	12°06′	.050	297	39.3	45.8	47.6	.166	.248	.271	364	37.8	43.8	46.0	.152	.221	.249
4B:																
10	10°00′	.073	300	35.5	44.0	46.4	.074	.153	.179	325	37.5	44.3	45.5	.091	.156	.169
15	11°00′	.073	320	36.0	45.0	46.8	.094	.187	.208	340	35.5	42.0	43.8	.085	.154	.174
22	11°30′	.080	380	40.5	49.5	52.4	.140	.250	.289	380	39.0	48.0	49.3	.124	.230	.247
Average	10°50′	.075	333	37.3	46.2	48.5	.101	.195	.223	348	37.2	44.8	46.2	.100	.179	.196
5:																
2-*I*	17°30′	.062	215	36.5	44.0	45.0	.211	.335	.352	-----	----	----	----	-----	-----	-----
6A:																
9-*I*	29°00′	.062	300	25.1	29.7	31.5	.151	.236	.274	-----	----	----	----	-----	-----	-----
3	23°50′	.077	215	31.5	36.2	38.1	.200	.289	.328	455	32.2	36.2	37.8	.212	.289	.319
I-average	26°25′	.070	258	28.3	33.0	34.8	.177	.266	.304	-----	----	----	----	-----	-----	-----
O-average	23°50′	.077	-----	----	----	----	-----	-----	-----	455	32.2	36.2	37.8	.212	.289	.319
6B:																
1	25°00′	.083	200	23.7	28.9	29.4	.081	.161	.170	300	22.6	28.5	29.4	.066	.155	.170
4	20°30′	.083	220	28.0	34.5	36.0	.103	.202	.227	220	30.0	35.0	37.2	.132	.210	.248
Average	22°45′	.083	210	25.8	31.7	32.7	.094	.184	.201	260	26.3	31.8	33.3	.101	.186	.212

[1] The outside and inside lanes have different curvatures at sites 2 and 29, and no outside lane data were obtained at sites 9 and 25. Because of these cases (as indicated by *I* for inside lane and *O* for outside lane), separate group averages for inside and outside lanes are given for some groups.

this study the maximum was only 0.083 foot per foot.

The family of curves in figure 6, used to represent current design practices, is based on a safe coefficient of side friction of 0.16 for speeds up to 60 miles per hour, 0.15 for 65 miles per hour, and 0.14 for 70 miles per hour.

Side Friction Utilized

One of the factors of highway design for which factual data have been seriously lacking is the coefficient of side friction that vehicles actually develop as they negotiate various curves. The coefficients of side friction developed on the horizontal curves included in this study were determined from the data recorded, using the following basic formula:

$$F=\frac{0.067V^2}{R}-S$$

where

F=coefficient of side friction.
V=speed in miles per hour.
R=radius of curve in feet.
S=superelevation in feet per foot.

The basic data for each of the curves included in the study and the calculated coefficients of side friction are shown in table 3. In this table the horizontal curves have first been arranged in groups according to degree of curvature. Each of these groups has been further divided into two subgroups, the first subgroup including curves having relatively low superelevations and the other subgroup including curves having the higher superelevations.

The superelevations used to separate the data into the subgroups were related to the curvatures. For 3- and 4-degree curves the division was made at a superelevation of about 0.04 foot per foot. This value increases as the degree of curvature increases, and for the sharper curves the division was made at about 0.08 foot per foot. The coefficients of side friction are shown for the average speed, for the 90-percentile speed, and for the 95-percentile speed on each curve.

Figure 7, showing separately for inside and outside lanes the relation of speed, coefficient of side friction, and superelevation, was plotted from the average values for each group of curves in table 3. The lower chart of each pair shows the average, 90-, and 95-percentile speeds for each curvature group; the upper chart shows the corresponding coefficient of side friction utilized in negotiating the various curves at the indicated speeds.

It may be noted from figure 7 that the operating speeds are about the same on horizontal curves of similar degree, regardless of the superelevations, within the limits of this study. This appears to be true for both the inside and outside lanes. The amount of super-

elevation, therefore, apparently had little or no effect on the operating speeds.

It follows, then, that the utilized coefficient of side friction was smaller when the superelevation was high than when it was low. For example, for the inside lanes (figure 7) on curves of 10 to 15 degrees the side friction for drivers traveling at the average speed was 0.17 when the superelevation was 0.050 foot per foot and 0.10 when the superelevation was 0.075 foot per foot. The high-speed drivers developed higher coefficients of side friction: At the 95-percentile speed, coefficients of side friction averaged 0.28 when the superelevation was 0.50 and 0.22 when the superelevation was 0.075 foot per foot. In both of these cases the difference in side friction between the low and higher superelevations was about the same, being 0.06 in the one example and 0.07 in the other. On curves of less than 7 degrees the difference was less, being in the neighborhood of 0.02 or 0.03.

Figure 7 also shows that the utilized coefficient of side friction generally increased as the degree of curvature increased, and that the coefficient was slightly smaller for the outside than for the inside lanes.

Critical Criterion of Superelevation

Since it was found that curvature affected the operating speeds on horizontal curves but that superelevation had little or no effect, the analysis was directed to the percentage of vehicles that exceeded safe speeds based on curvature and superelevation. Superelevation is normally expressed in units of feet of rise per foot of pavement width, and curvature in degrees. To facilitate the determination of the number of vehicles that were operating at unsafe speeds in relation to the geometric features of the highway, it was found desirable to express the superelevation in terms of feet of rise per foot of pavement width per degree of curvature, a term hereafter identified as the *unit of superelevation.*

An extremely high degree of correlation was found to exist when this unit of superelevation was related to the percentage of vehicles ex-

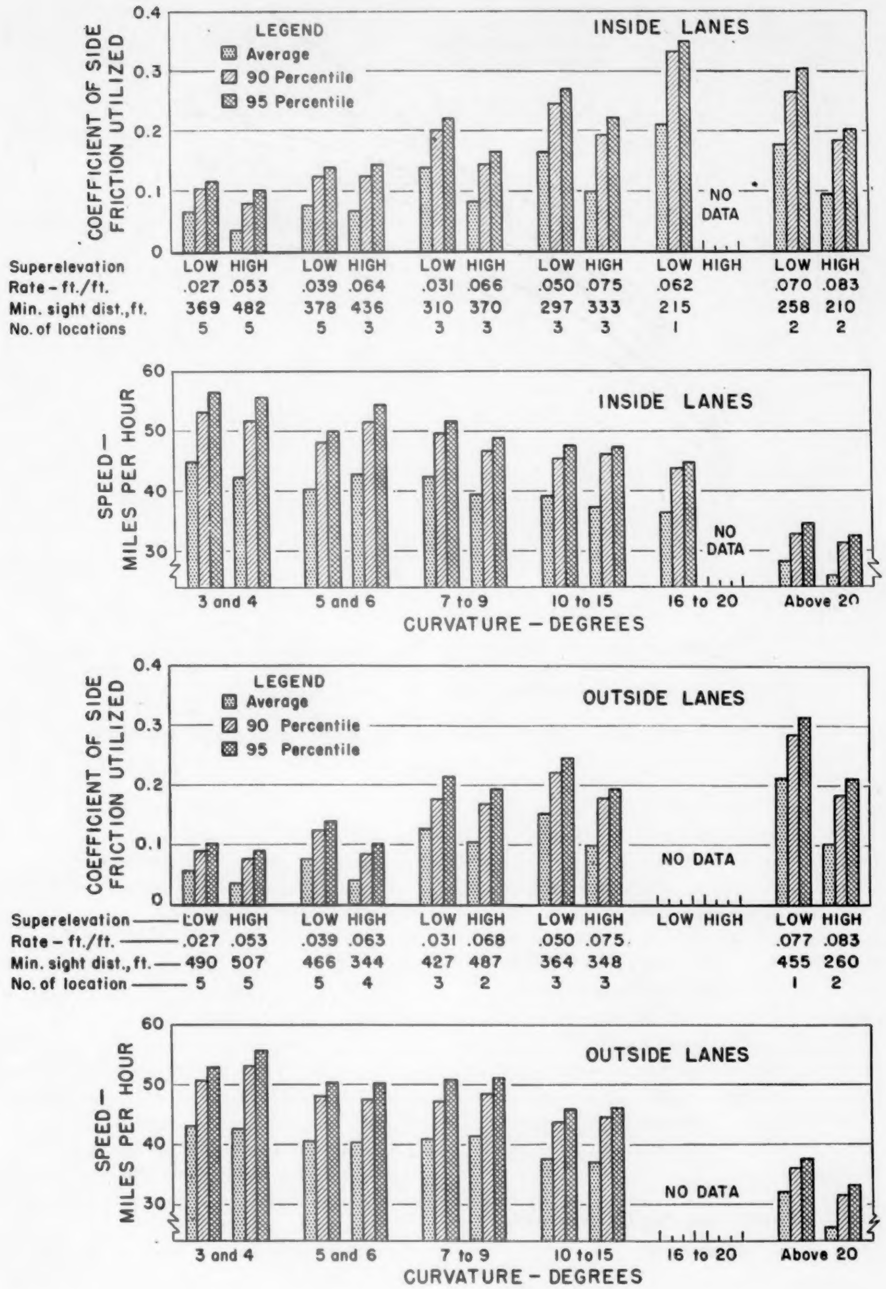

Figure 7.—(Above) ***Relation between speed, coefficient of side friction, and superelevation***

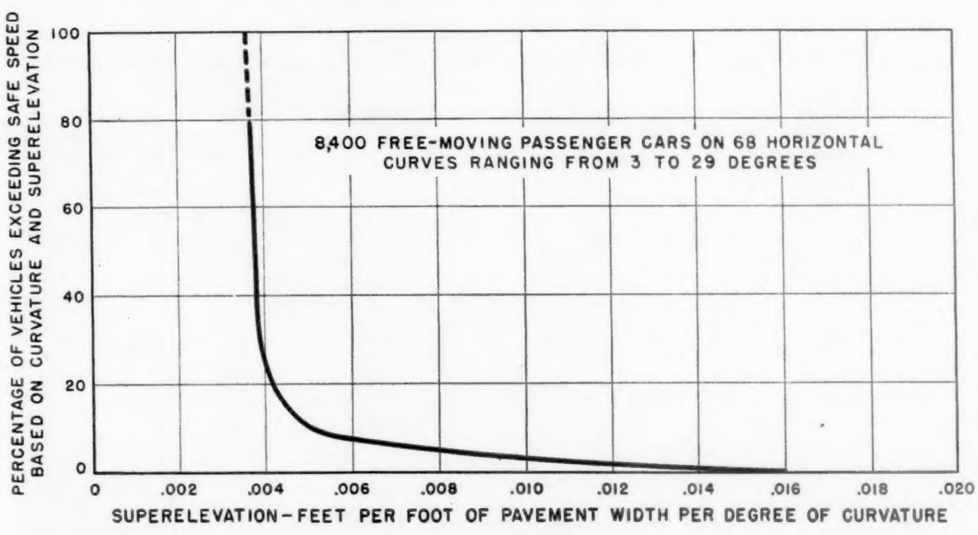

Figure 8.—Effect of superelevation on percentage of vehicles exceeding safe speed.

ceeding the safe speed, as shown in figure 8. Only one curve is shown for both lanes of travel, because the individual curves for the inside and outside lanes coincide. This is easily understood if it is remembered that the curvature was measured to the center of the highway, not separately for each lane, and that operating speeds were nearly the same in both directions of travel. The actual plotting points are not shown in figure 8, but they were all very close to the average curve, indicating a very consistent relation between the two variables. This was the case even though both sharp and moderate curves were included over the entire range of unit superelevations used.

The curve breaks very sharply at a unit

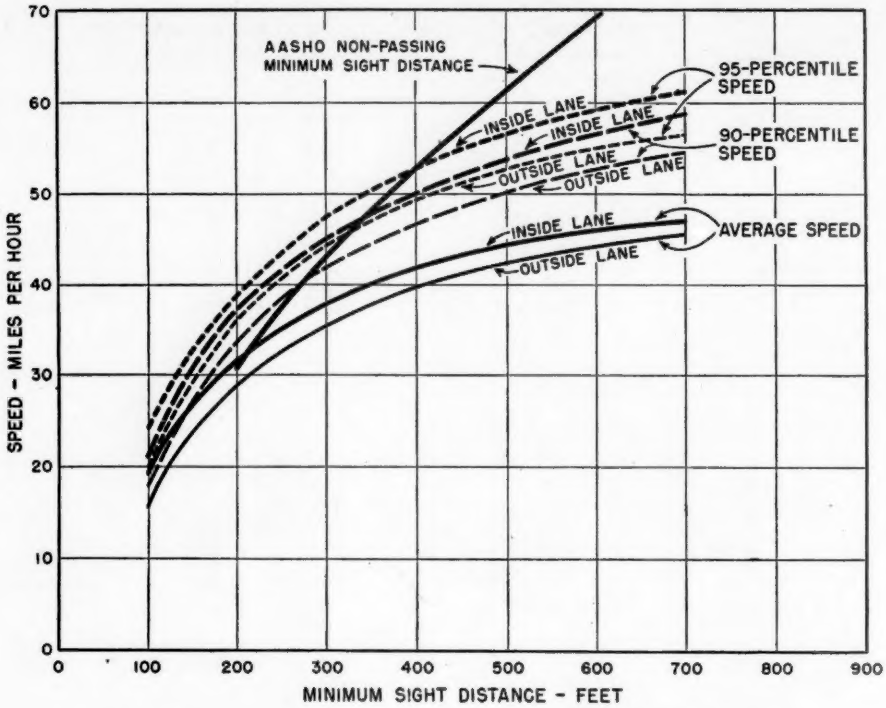

Figure 9.—Relation between speed and minimum sight distance.

superelevation of about 0.005. This indicates that for conditions included in this study few vehicles exceed a safe speed on horizontal curves designed with a unit superelevation of more than 0.005 foot per foot of pavement per degree of curvature. For unit superelevations less than this amount, however, a high percentage of the vehicles will exceed the speeds considered safe for the combination of curvature, superelevation, and coefficients of side friction as shown in figure 6. Although there are curves with unit superelevations of less than 0.005 foot per foot per degree, specifications in modern design standards generally provide higher rates.

Speed–Minimum Sight Distance Relation

In addition to consideration of curvature and superelevation, modern design practices require sight distances adequate for safe operation. This study provides data for an analysis of the extent to which sight distance on horizontal curves affects driver speeds. The relation between speed and sight distance, neglecting the effect of curvature, is shown in figure 9, the curves being based on the data in table 1.

One fact clearly brought out in the figure is that, at a given minimum sight distance, vehicle speeds are higher on the inside lanes than on the outside lanes. At a given location the observed speeds were about the same in both lanes but, because the sight distances are longer for a driver traveling in the outside lane than in the inside lane, the relation shown in figure 9 is obtained. On an average, the minimum sight distance in the outside lane was about 20 percent higher than in the inside lane. Taking this into consideration, it appears that the drivers in the inside lanes are more apt to exceed safe speed with respect to sight-distance requirements than when they are traveling in the outside lanes.

As previously stated, the relation between available sight distance and speed as shown in figure 9 entirely ignores the fact that at the locations with the shorter sight distances the curvatures are generally sharper than at the locations with the longer sight distances. The change in speed with a change in sight distance as shown in figure 9 may therefore have been caused largely by the driver's reaction to curvature rather than sight distance.

As may be observed from figure 9, the operating speeds are related to the minimum sight distance, but the data at the individual locations vary considerably about the established theoretical relations shown in table 4. This is indicated by the relatively high standard errors, which are an index of the dispersion of the individual points about the curves. These standard errors are much greater than those for speed as related to curvature which are shown in table 2. This was the case even though every effort was made to determine whether there was not a more direct relation between speed and sight distance. The hyperbolic equations shown in table 4 were found by the method of least squares to give the best fit of the individual points to the curves. Other types of general equations tried were the straight line, parabola, and two additional hyperbolas.

Although the speeds of drivers on horizontal curves are not principally governed by sight-distance conditions, it is of interest to examine the extent to which drivers exceed safe speeds as determined by various sight-distance criteria.

Included in figure 9 is a curve showing the A.A.S.H.O. recommended nonpassing minimum sight distance for given speeds. The average driver was found to operate his car at a speed from which he could have stopped safely, according to these standards, on all horizontal curves for which the minimum sight distance was about 200 feet or more. The high-speed (95-percentile) drivers operated their cars at speeds which would permit them to stop within the available sight distance only when sight distances were above 400 feet.

Since drivers do not control their speeds to conform with the available sight distances as related to total stopping distances, it is of interest to determine what portion of the total stopping distances, for the speeds actually observed, is provided by the available sight distance. Results from several studies show the distances necessary to bring vehicles to a stop from various speeds. Among other things, these tests show the braking distance, which is the distance required to stop from the moment the brakes are applied until the car comes to a standstill. Not so readily determinable is the driver (or total) stopping distance, which is the braking distance plus the distance the car travels during the driver perception and reaction time. Table 5 shows the braking and driver stopping distances

Table 4.—Theoretical equations showing relation between speed and minimum sight distance

Speed	Equation [1]	Standard error (adjusted)	Coefficient of correlation (adjusted)
Inside lanes:		*M.p.h.*	
Average	$V_a=56.8-\frac{75.4}{S+1}$	4.55	0.613
90-percentile	$V_{90}=69.5-\frac{97.0}{S+1}$	5.14	.643
95-percentile	$V_{95}=74.6-\frac{108.8}{S+1}$	5.24	.708
Outside lanes:			
Average	$V_a=55.6-\frac{80.2}{S+1}$	4.14	.623
90-percentile	$V_{90}=66.1-\frac{96.3}{S+1}$	4.64	.657
95-percentile	$V_{95}=68.8-\frac{97.7}{S+1}$	5.14	.615

[1] V=speed in miles per hour; S=minimum sight distance in hundreds of feet.

Table 5.—Relation of braking and driver stopping distances to speed

Speed	Braking distance from study [1]			Driver stopping distance [2]			
	15-percentile	Average	85-percentile	From study [3]		A.A.S.H.O. (No safety factor)	A.A.S.H.O. (1.25 safety factor)
				15-percentile	85-percentile		
M.p.h.	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
20	16	22	29	110	123	115	120
30	36	45	63	168	195	180	192
40	64	80	118	226	280	252	275
50	100	134	210	283	393	331	368
60	144	205	336	342	534	427	484
70	196	310	510	402	716	533	614

[1] *Braking distances of vehicles from high speeds and tests of friction coefficients*, by O. K. Normann. PUBLIC ROADS, vol. 27, No. 8, June 1953.
[2] Includes driver perception and reaction distance.
[3] Perception and reaction distance same as in A.A.S.H.O. policy.

This speed is recorded in the third column of table 6. The seventh column shows that none of the drivers observed on the curve at this site exceeded a speed of 30.6 miles per hour.

The data in tables 6 and 7 were plotted as smooth curves in figure 11, which shows the percentages of vehicles exceeding the speeds from which drivers can brake or stop within the available sight distances on the horizontal curves. Four pairs of curves are shown, each pair consisting of information for the inside lane and for the outside lane.

At locations where the minimum sight distance is 400 feet or longer, few drivers exceed the speed from which they are able to stop within the available sight distance, regardless

according to the A.A.S.H.O. recommended design standards for rural highways and the results of recent braking distance tests.

The 15-percentile, average, and 85-percentile braking distances are those recorded during a comprehensive study of braking distances of vehicles.[3] These percentiles were used, rather than the 90- and 95-percentiles used elsewhere in this article, because they were the 2 extremes that could be obtained with reasonable accuracy from the braking-distance information. The 15-percentile braking distance is the distance within which 15 percent of the vehicles with the best brakes could stop, and the 85-percentile braking distance is the distance within which 85 percent of the vehicles could stop, with only 15 percent requiring longer distances.

Figure 10 shows graphically the data contained in table 5. The individual curves are each identified by a number corresponding to the appropriate column in table 5. Figure 10 shows, for example, that for speeds above 60 miles per hour the distance within which 85 percent of the vehicles will stop after the brakes are applied (curve 4) is greater than the driver (total) stopping distance for the 15 percent of the drivers that made the shortest stops (curve 5).

The various relations between speed and distance under the several conditions represented in figure 10 were used to relate driving speeds on horizontal curves to sight-distance conditions. The object was to use each of the several curves in figure 10 as a criterion to obtain a measure of the relative ability of drivers to stop their vehicles within the available sight distances from the speeds at which they were traveling on the various horizontal curves.

The percentages of vehicles traveling on horizontal curves at speeds exceeding those obtained from the several assumed criteria are shown in tables 6 and 7 for the inside and outside lanes, respectively. Table 6 shows, for example, that at site 1 the minimum sight distance was 200 feet. Curve 6 in figure 10 shows that 85 percent of the drivers during the braking distance tests could stop within 200 feet from a speed of 30.6 miles per hour.

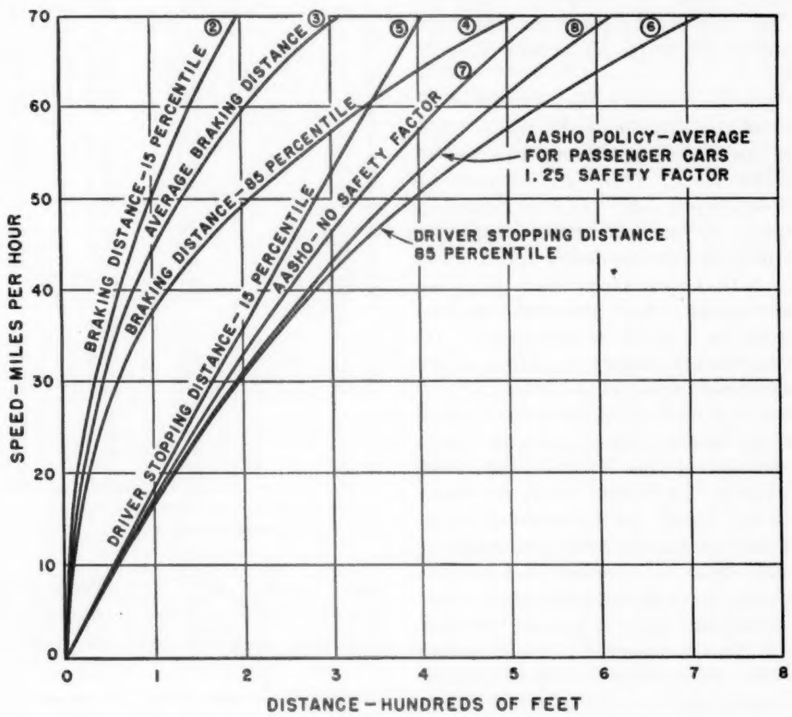

Figure 10.—Relation of braking and stopping distances to speed.

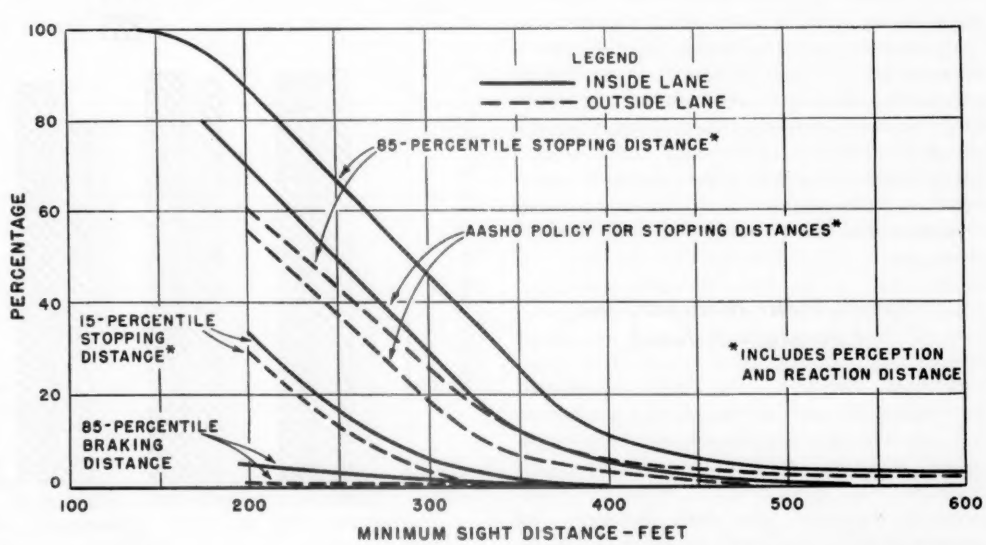

Figure 11.—Percentage of vehicles exceeding the speed from which drivers can brake or stop within available sight distance.

[3] *Braking distances of vehicles from high speeds and tests of friction coefficients*, by O. K. Normann. PUBLIC ROADS, vol. 27, No. 8, June 1953.

of which criterion is used. At locations having sight distances shorter than 400 feet, however, there is wide divergence in the percentages of vehicles traveling in excess of those speeds which conform to the stopping distances established by the various criteria being tested. Where the minimum sight distance is 200 feet, for example, 86 percent of the drivers in the inside lanes exceed the speed from which 85 percent could have stopped safely. Stated another way, 86 percent of the drivers exceed the speed from which 15 percent could not have stopped. This does not necessarily indicate an unsafe condition if it could be assumed that the faster drivers were those with the better brakes, or were more alert and consequently might have shorter-than-average perception and reaction time. It strongly suggests, however, that few drivers could have stopped had an object suddenly come into view in their lane.

With a minimum sight distance of 200 feet, 34 percent of the drivers in the inside lanes exceed the speed from which only the best 15 percent could stop. This can scarcely be considered safe operation. At this minimum sight distance, 70 percent of the drivers in the inside lanes exceed the design speed based on the A.A.S.H.O. standards for nonpassing sight distances only. For each of the criteria, the percentage of vehicles exceeding the safe speed is considerably lower for vehicles in the outside lanes than in the inside lanes.

Returning to a sight distance of 400 feet, 10 percent of the drivers exceed the speed from which 85 percent of the vehicles could have stopped in less than 400 feet. Only 5 percent of the vehicles exceed the speed from which they could stop within the minimum nonpassing stopping distance recommended by the A.A.S.H.O. It is apparent, therefore, that when the minimum sight distance is 400 feet or longer few drivers observed in these studies overdrove the sight distance on horizontal curves based on any of the criteria. When sight distances are shorter than 400 feet, the percentage of drivers exceeding the speeds which permit braking within the available sight distance, with allowance for perception and reaction time, increases rapidly with a decrease in the sight distance. Very few of the drivers, however, under any of the conditions studied, were traveling faster than the speed from which they could have stopped within the available sight distance when braking distance alone is considered, with no allowance for driver perception and reaction time.

Speed, Sight Distance, and Curvature Related

A high correlation has been established between speed and curvature, and a relation, but one with low correlation, has been established between speed and minimum sight distance. No close relation could be found between curvature and sight distance. All three variables must be considered in combination, however, to obtain their true effect on driver behavior. The combined relation between average speed, minimum sight distance, and curvature is shown in figures 12 and 13. The study locations have been combined into several sight-distance and curvature groups giving a range of conditions which may be applicable to the normal highway in the area.

Table 6.—Speeds from which vehicles could stop within available sight distance, based on various assumed criteria, and percentages of vehicles exceeding those speeds, on inside lanes of 2-lane highways

Study site No.	Minimum sight distance	Stopping speed as determined by using available sight distance and—				Percentage of observed vehicles exceeding calculated stopping speeds based on—			
		85-percentile driver stopping distance (curve 6 [1])	A.A.S.H.O. policy for stopping distance (curve 8 [1])	15-percentile driver stopping distance (curve 5 [1])	85-percentile braking distance (curve 4 [1])	85-percentile driver stopping distance	A.A.S.H.O. policy for stopping distance	15-percentile driver stopping distance	85-percentile braking distance
	Feet	*M.p.h*	*M.p.h.*	*M.p.h.*	*M.p.h.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	200	30.6	31.0	36.0	49.0	0	0	0	0
2	215	32.3	32.5	39.0	51.0	81.6	80.7	33.5	0
3	215	32.3	32.7	38.5	50.5	48.3	44.8	10.3	0
4	220	33.0	33.8	39.0	51.0	18.7	13.8	1.3	0
5	236	35.0	35.8	41.7	52.1	73.0	68.4	36.9	3.3
6	256	37.0	37.6	45.5	54.0	80.4	78.1	15.2	1.2
7	285	40.4	41.5	51.5	56.2	21.1	16.6	0	0
8	297	41.7	42.6	52.0	57.0	44.5	39.2	9.8	2.8
9	300	42.0	43.0	53.0	57.0	0	0	0	0
10	300	42.0	43.0	53.0	57.0	20.0	15.6	.4	0
11	303	42.3	43.0	53.1	57.0	73.4	70.2	20.7	9.9
12	303	42.3	43.0	53.1	57.0	44.7	39.1	3.9	.9
13	308	42.8	43.8	54.0	57.9	43.1	32.3	.8	0
14	320	43.9	45.0	56.0	59.0	15.9	10.6	0	0
15	320	43.9	45.0	56.0	59.0	14.2	5.0	0	0
16	324	44.2	45.5	58.8	57.0	42.5	32.5	2.7	3.6
17	342	46.0	47.3	60.2	60.0	25.8	19.7	0	0
18	350	46.4	48.1	61.0	61.0	24.6	16.7	.6	.6
19	360	47.3	49.0	63.0	61.6	24.5	18.4	3.3	3.9
20	371	48.2	50.0	64.4	62.3	11.5	6.9	0	0
21	377	48.7	50.6	65.2	62.6	73.3	61.2	.9	6.1
22	380	49.0	50.9	66.0	62.8	11.8	7.3	0	0
23	400	50.5	52.9	70.0	64.0	10.6	6.0	0	.1
24	407	51.0	53.7	70.0+	64.5	14.8	6.0	0	.6
25	420	52.0	54.7	70.0+	65.3	2.3	.9	0	0
26	435	53.1	55.9	70.0+	65.0	.6	0	0	0
27	440	53.5	56.0	70.0+	66.0	11.1	6.8	0	0
28	450	54.2	57.0	70.0+	66.2	10.5	5.4	0	0
29	460	55.0	58.0	70.0+	67.5	12.0	6.6	1.0	0
30	469	55.4	58.9	70.0+	67.9	2.3	.9	0	0
31	470	55.6	59.0	70.0+	68.0	1.8	.4	0	0
32	490	56.9	60.5	70.0+	65.3	5.1	0	0	1.7
33	500	57.6	61.1	70.0+	69.5	3.9	3.9	0	1.0
34	500	57.6	61.1	70.0+	69.5	1.4	.6	0	0
35	510	58.2	62.0	70.0+	70.0	2.0	.7	0	0

[1] Curve numbers in fig. 10.

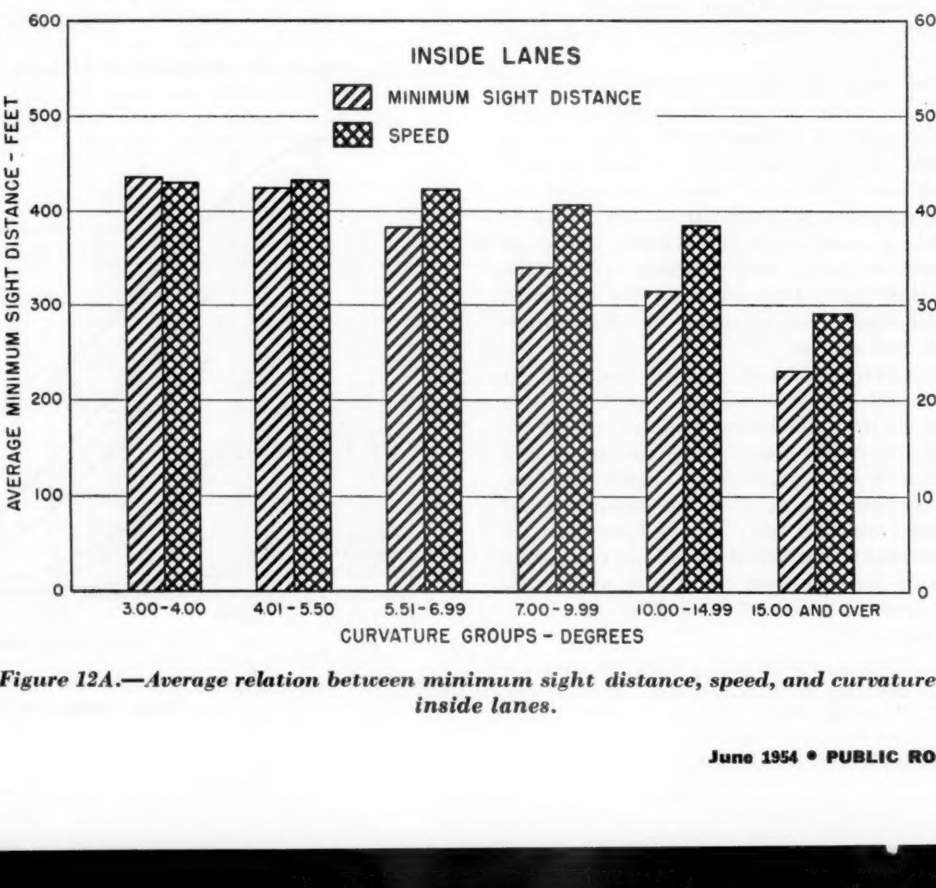

Figure 12A.—Average relation between minimum sight distance, speed, and curvature on inside lanes.

Table 7.—Speeds from which vehicles could stop within available sight distance, based on various assumed criteria, and percentages of vehicles exceeding those speeds, on outside lanes of 2-lane highways

Study site No.	Minimum sight distance	Stopping speed as determined by using available sight distance and—				Percentage of observed vehicles exceeding calculated stopping speeds based on—			
		85-percentile driver stopping distance (curve 6 [1])	A.A.S.H.O. policy for stopping distance (curve 8 [1])	15-percentile driver stopping distance (curve 5 [1])	85-percentile braking distance (curve 4 [1])	85-percentile driver stopping distance	A.A.S.H.O. policy for stopping distance	15-percentile driver stopping distance	85-percentile braking distance
	Feet	*M.p.h.*	*M.p.h.*	*M.p.h.*	*M.p.h.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
4	220	33.0	33.8	39.0	51.0	26.5	19.4	1.8	0
2	220	33.0	33.8	39.0	51.0	80.3	76.4	45.5	0
1	300	42.0	43.0	53.0	57.0	0	0	0	0
30	316	43.7	44.8	55.6	58.2	34.9	26.3	2.2	1.9
14	320	43.9	45.0	56.0	59.0	10.4	6.2	0	0
8	323	44.1	45.2	56.2	59.2	34.9	28.0	0	0
10	325	44.5	45.4	59.5	57.0	5.2	3.5	0	0
15	340	45.7	47.2	60.0	61.2	.9	.5	0	0
19	360	47.3	49.0	63.0	61.6	5.8	3.6	0	.1
18	375	48.5	51.5	65.4	62.5	17.3	7.6	0	0
13	377	48.7	50.6	65.2	62.6	2.4	1.9	0	0
22	380	49.0	50.9	66.0	62.8	5.8	2.2	0	0
7	391	50.0	52.0	68.5	62.5	1.7	1.0	0	0
23	400	50.5	52.9	70.0	64.0	11.5	6.5	0	0
31	430	52.8	55.2	70.0+	65.9	2.7	0	0	0
17	439	52.9	57.0	70.0+	66.1	5.8	1.1	0	0
27	440	53.5	56.0	70.0+	66.0	0	0	0	0
5	452	54.2	57.2	70.0+	66.2	0	0	0	0
16	452	54.2	57.2	70.0+	66.2	1.3	0	0	0
6	453	54.3	57.3	70.0+	66.3	1.1	.4	0	0
3	455	54.2	57.0	70.0+	67.0	0	0	0	0
26	460	55.0	58.0	70.0+	67.5	1.2	.5	0	0
29	460	55.0	58.0	70.0+	67.5	27.4	10.0	0	1.0
12	489	57.0	62.0	70.0+	70.0+	1.8	0	0	1.1
34	500	57.6	61.1	70.0+	69.5	3.0	1.2	0	.1
32	500	57.6	61.1	70.0+	69.5	1.6	0	0	0
35	520	58.9	63.0	70.0+	70.0+	1.9	0	0	0
11	526	59.2	63.4	70.0+	70.0+	2.4	0	0	0
33	530	59.4	63.7	70.0+	70.0+	3.8	.7	0	0
21	546	60.5	65.0	70.0+	70.0+	3.5	.7	0	0
24	550	60.9	65.0	70.0+	70.0+	1.8	.7	0	0
28	557	61.6	66.5	70.0+	70.0+	2.2	0	0	0
20	655	66.5	70.0+	70.0+	70.0+	0	0	0	0

[1] Curve numbers in figure 10.

Figure 12A shows, for the inside lanes on the curves, the manner in which average speed and minimum sight distance vary with the degree of curvature. It will be noted that the average minimum sight distance decreases as the curvature increases. The average speed also has a tendency to decrease with an increase in curvature, but speed is not materially affected by changes in curvature between the limits of 3 and 10 degrees. For curves of 10 degrees or more, a significant reduction in speed accompanies an increase in the degree of curvature.

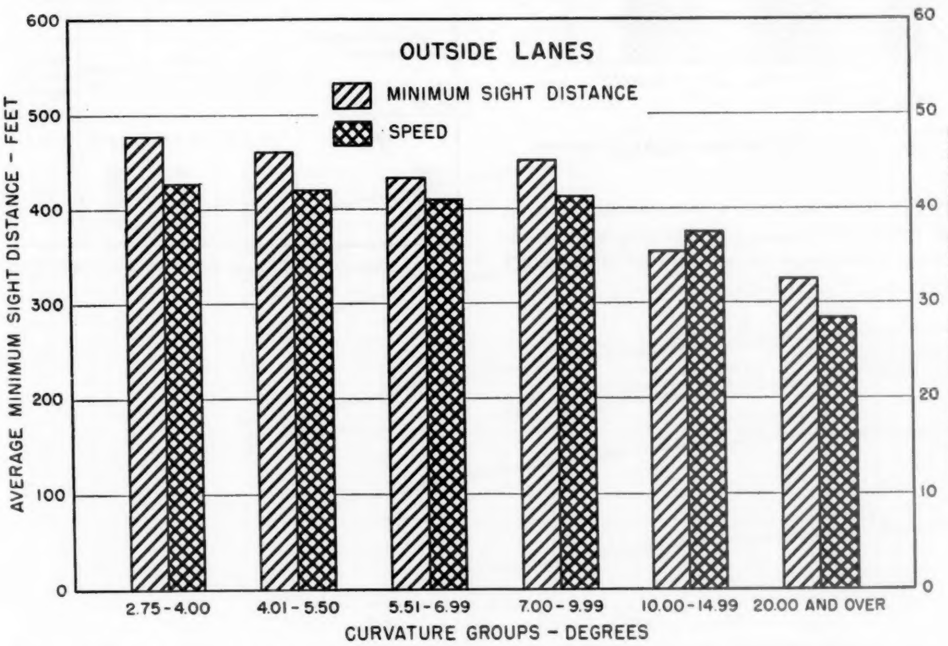

Figure 12B.—Average relation between minimum sight distance, speed, and curvature, on outside lanes.

Figure 12B shows comparable information for the outside lanes. Neither the minimum sight distance nor the average speed in the outside lanes is reduced appreciably as the curvature increases to 10 degrees. The average speed is reduced to about 28 miles per hour on curves of 20 degrees or over where the average minimum sight distance is 325 feet.

Figure 13 shows separately for the inside and outside lanes the average curvature and speed as related to the minimum sight distance. For the inside lanes, the average curvature decreases without exception with each increment of minimum sight distance. The average speed, however, increases from 34 miles per hour to something over 40 miles per hour with a change in minimum sight distance from 200 to 350 feet, while at the same time the curvature decreases from 16 degrees to 7 degrees. Neither average curvature nor speed show marked change as the minimum sight distance increases above 350 feet.

Conditions for the outside lanes are somewhat at variance with those for the inside lanes. While changes in sight distance are accompanied by changes in degree of curvature in much the same manner as for the inside lanes, average speeds in the outside lanes are progressively higher for successive increases in minimum sight distance throughout the sight distance range.

Figures 12 and 13 show the average speeds obtained on horizontal curves having curvatures and sight distances varying within certain fixed limits. There is considerable range in sight distance on curves having the same degree of sharpness, however, and different locations having about the same minimum sight distance have a considerable range in the sharpness of the curvature.

Figure 14 shows the average, 90-percentile, and 95-percentile speeds, respectively, for horizontal curves throughout the range of curvature and sight-distance conditions included in this study, and indicates the speeds that would most likely be found on horizontal curves on existing two-lane highways with the conditions of speed and sight distance generally prevailing in the areas included in this study. The relations shown were obtained by applying the method of least squares to the basic data for the inside and outside lanes combined. The curves in this figure represent speed contours. Shown on each part of the figure is the standard error within which the speeds can be assumed to be correct.

This figure shows that the sight distance has a comparatively small effect on vehicle speeds, whereas curvature has a considerable effect. With a constant curvature (reading horizontally) the average change in speed is about 0.8 mile per hour for each 100-foot change in sight distance. With a constant sight distance (reading vertically) the average

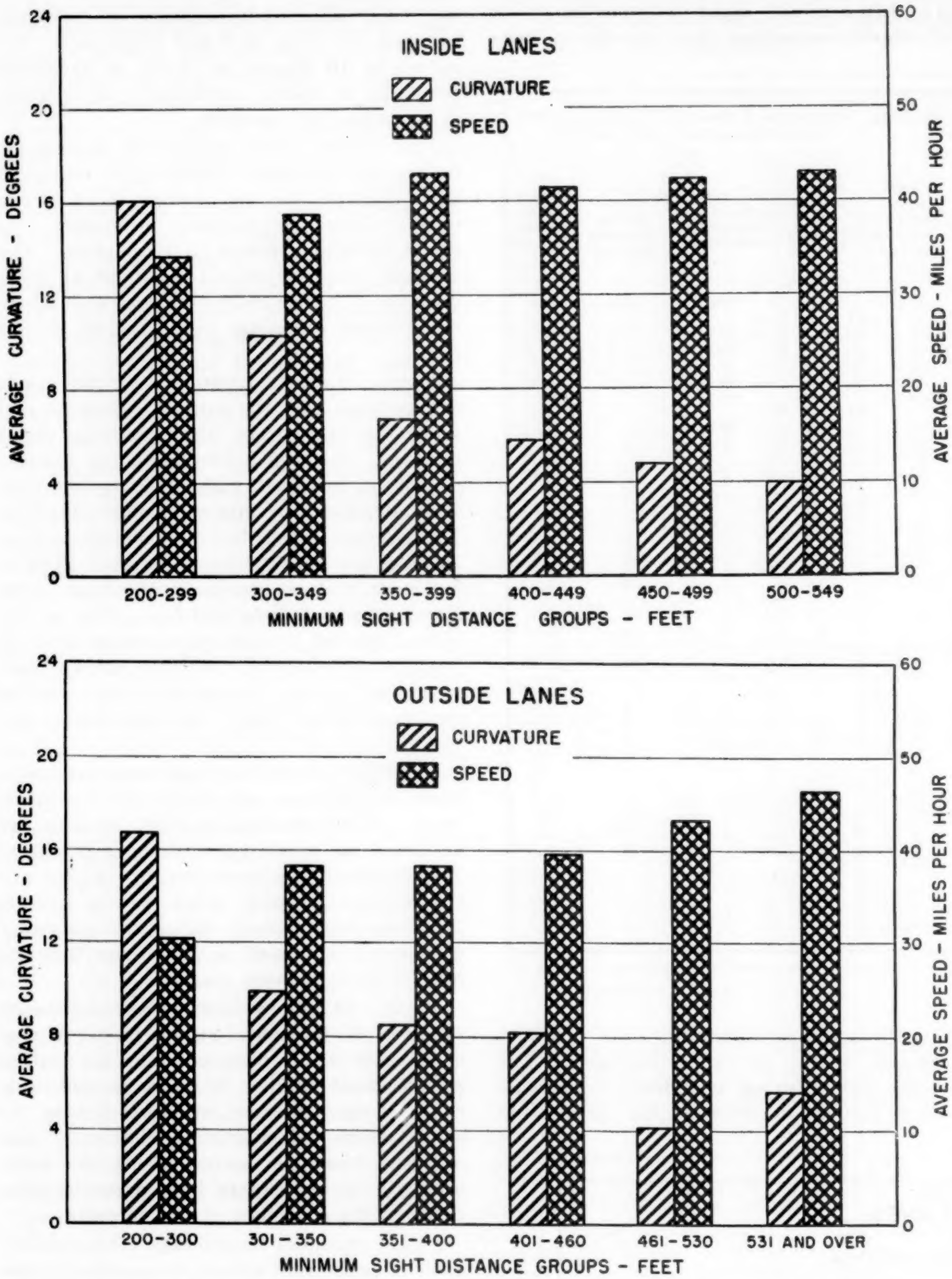

Figure 13.—Average relation between curvature, speed, and minimum sight distance.

speed changes uniformly about 0.7 mile per hour for each 1-degree change in curvature. As previously stated, however, the relation between sight distance and curvature is such that a 3-degree change in curvature is approximately equivalent to a 100-foot change in sight distance. Then, since a 3-degree change in curvature causes a 2.1-mile per hour change in average speed (with sight distance constant) and a 100-foot change in sight distance causes an 0.8-mile per hour change in average speed (with curvature constant), curvature causes nearly three times as great a change in speed as sight distance, under comparable conditions. This is as true for the 90- and 95-percentile speeds as for the average speed.

Comparison of Driver Behavior on Horizontal and Vertical Curves

Along with this study, carried out as a cooperative project by the Bureau of Public Roads and the New York State Department of Public Works, a companion study on vertical curves was included in the program.[4] It is interesting to compare the results of these two studies, as shown in table 8.

It will be noted that with the same minimum sight distance, vehicle speeds are considerably lower on horizontal curves than on vertical curves. The difference in speed is greater when the sight distance is short than when it is long. This tends to confirm the conclusion that sight distance has only a minor influence on speeds on horizontal or vertical curves. If sight distance were the controlling factor there would be the same reduction in speed with a reduction in sight distance on the vertical curves as on the horizontal curves. Since this was not the case, it is apparent that the primary influencing factor was centrifugal force which is present on horizontal but not on vertical curves.

[4] See footnote 1, p. 27.

Table 8.—Comparison of vehicle speeds on vertical and horizontal curves having the same minimum sight distances

Minimum sight distance[1]	Average speed on—		95-percentile speed on—	
	Vertical curves	Horizontal curves	Vertical curves	Horizontal curves
Feet	*M.p.h.*	*M.p.h.*	*M.p.h.*	*M.p.h.*
200	42	30	54	37
300	45	37	56	46
400	46	41	57	51
500	46	43	58	54

[1] Sight distance in both cases measured to a 4-inch object.

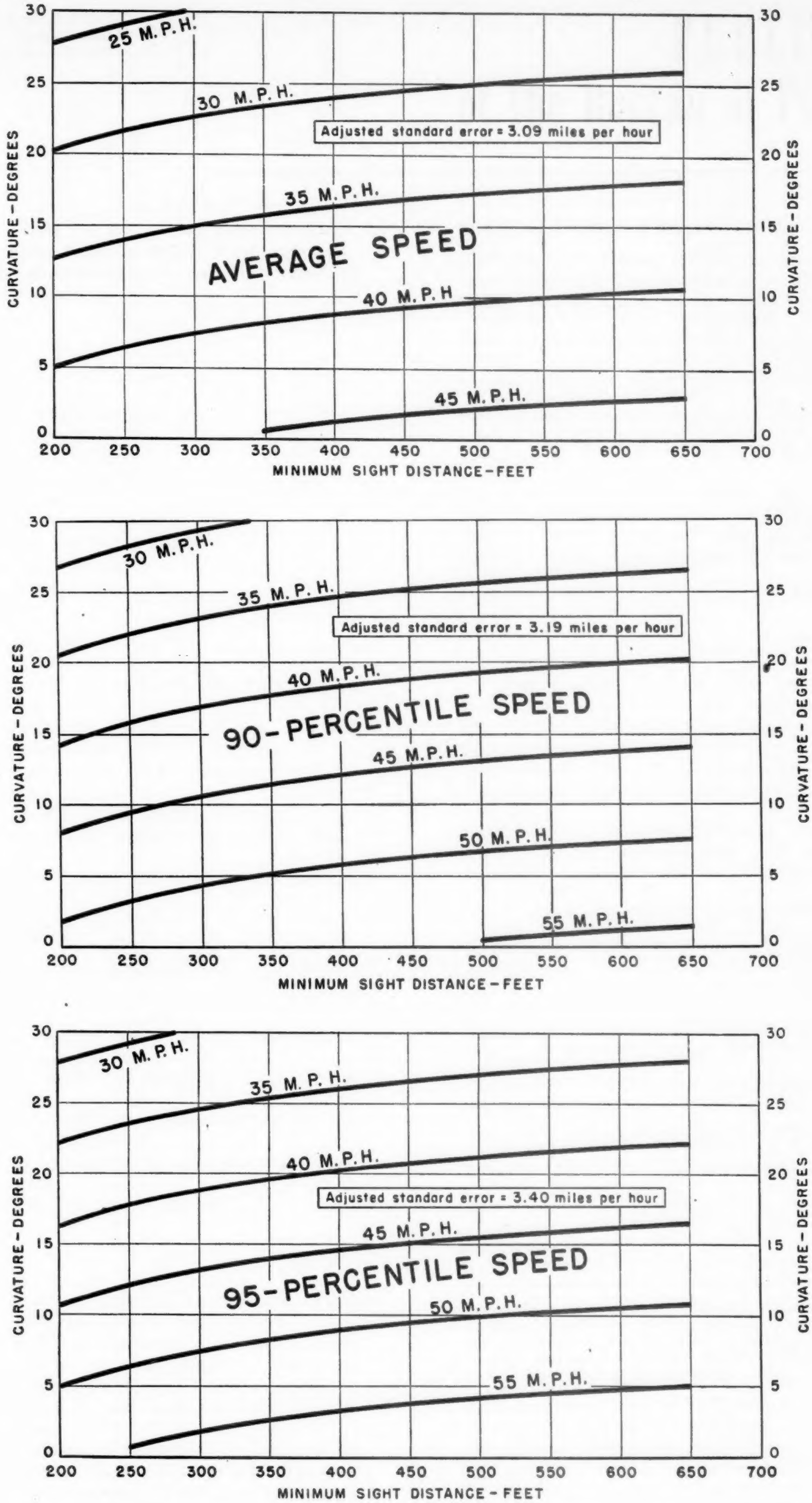

Figure 14.—Relation between minimum sight distance, curvature, and average speed.

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STATUS OF FEDERAL-AID HIGHWAY PROGRAM

FOR OFFICIAL USE

AS OF APRIL 30, 1954

(Thousand Dollars)

STATE	UNPROGRAMMED BALANCES	ACTIVE PROGRAM											
		PROGRAMMED ONLY			PLANS APPROVED, CONSTRUCTION NOT STARTED			CONSTRUCTION UNDER WAY			TOTAL		
		Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles
Alabama	$7,090	$16,258	$8,487	334.1	$8,936	$4,531	168.0	$44,621	$22,201	511.5	$69,815	$35,219	1,013.6
Arizona	2,888	6,174	4,405	127.2	1,482	1,052	37.5	6,513	4,567	83.3	14,169	10,024	248.0
Arkansas	7,858	8,413	4,709	360.4	5,299	2,658	140.9	14,542	7,252	301.7	28,254	14,619	803.0
California	8,406	24,430	11,715	163.2	20,901	10,690	91.8	83,978	41,128	199.7	129,309	63,533	454.7
Colorado	10,285	2,764	1,533	40.8	1,241	692	41.8	19,227	10,538	213.9	23,232	12,763	296.5
Connecticut	9,871	5,238	2,464	7.6	251	125	.2	9,256	4,611	26.8	14,745	7,200	34.6
Delaware	2,333	2,673	1,363	12.2	2,500	1,601	18.3	4,652	2,319	24.4	9,825	5,283	54.9
Florida	4,894	25,614	12,969	406.4	4,558	2,369	68.7	20,607	10,806	316.3	50,779	26,144	791.4
Georgia	15,078	11,985	6,127	196.7	7,425	3,516	132.4	39,392	18,717	596.6	58,802	28,360	925.7
Idaho	2,050	8,175	5,189	179.6	6,398	3,993	100.1	12,778	7,925	218.5	27,351	17,107	498.2
Illinois	15,493	36,038	19,152	352.3	23,549	11,671	186.7	63,538	34,482	347.8	123,125	65,305	886.8
Indiana	11,768	42,878	22,823	201.3	16,708	8,375	107.2	20,562	10,795	94.4	80,148	41,993	402.9
Iowa	4,193	17,103	9,084	705.5	11,694	6,228	427.1	19,294	10,608	600.4	48,091	25,920	1,733.0
Kansas	8,580	11,919	5,995	1,041.8	6,395	3,301	325.3	14,873	7,435	651.3	33,187	16,731	2,018.4
Kentucky	7,989	11,525	6,137	167.9	6,638	3,323	72.5	22,294	11,560	238.6	40,457	21,020	479.0
Louisiana	4,652	18,639	9,308	124.1	13,101	5,485	71.6	24,702	11,948	115.2	56,442	26,741	310.9
Maine	5,349	3,580	1,860	25.9	617	318	4.9	12,175	6,080	89.5	16,372	8,258	120.3
Maryland	6,854	15,744	8,212	120.1	3,469	1,870	21.7	7,770	3,884	37.4	26,983	13,966	179.2
Massachusetts	5,913	5,079	2,675	5.4	11,167	5,522	7.1	46,880	22,134	35.7	63,126	30,331	48.2
Michigan	12,166	33,512	16,347	399.9	11,591	5,753	257.8	38,839	18,467	232.7	83,942	40,567	890.4
Minnesota	7,979	14,178	7,106	1,100.5	11,207	5,968	609.0	17,073	8,983	243.5	42,458	22,057	1,953.0
Mississippi	7,515	8,801	4,494	280.0	6,477	3,346	174.7	20,024	10,072	529.7	35,302	17,912	984.4
Missouri	12,236	19,180	10,060	809.4	8,758	4,447	263.2	52,310	25,805	474.6	80,248	40,312	1,547.2
Montana	5,178	19,383	11,782	474.2	4,955	3,204	216.7	19,906	11,981	336.4	44,244	26,967	1,027.3
Nebraska	12,838	17,327	9,156	607.8	10,446	5,440	273.1	12,028	6,607	312.1	39,801	21,203	1,193.0
Nevada	6,459	4,042	3,380	156.0	113	95	23.2	8,685	7,202	171.4	12,840	10,677	350.6
New Hampshire	2,377	5,353	2,676	30.6	596	274	5.6	7,347	3,751	37.1	13,296	6,701	73.3
New Jersey	10,457	4,874	2,430	54.4	10,026	2,470	3.6	20,730	10,104	25.1	35,630	15,004	83.1
New Mexico	4,949	3,198	2,027	82.2	2,709	1,707	71.8	11,420	7,100	256.9	17,327	10,834	410.9
New York	7,480	103,792	53,963	171.2	45,186	22,623	216.1	150,049	70,722	295.2	299,027	147,308	682.5
North Carolina	8,395	24,404	12,171	456.3	4,284	2,104	103.4	37,994	17,673	508.2	66,682	31,948	1,067.9
North Dakota	3,603	8,597	4,315	1,022.4	6,899	3,450	446.6	6,678	3,492	354.0	22,174	11,257	1,823.0
Ohio	17,813	18,910	9,603	92.9	7,088	4,014	38.9	86,504	40,016	136.7	112,502	53,633	268.5
Oklahoma	11,047	17,214	9,393	246.3	6,965	3,672	133.5	14,042	7,470	186.5	38,221	20,535	566.3
Oregon	3,473	4,303	2,534	46.1	4,028	2,427	72.1	12,870	7,790	177.8	21,201	12,751	296.0
Pennsylvania	16,015	28,039	13,810	60.0	15,441	7,689	51.4	95,116	46,490	180.8	138,596	67,989	292.2
Rhode Island	3,305	4,408	2,204	36.0	1,504	752	13.4	7,421	3,708	23.2	13,333	6,664	72.6
South Carolina	7,049	9,581	5,178	225.8	4,067	2,124	183.6	14,510	7,167	450.2	28,158	14,469	859.6
South Dakota	2,127	13,403	7,656	715.8	2,184	1,259	129.6	8,886	4,966	446.1	24,473	13,881	1,291.5
Tennessee	8,292	15,273	7,615	365.8	10,103	5,055	348.8	33,033	15,042	322.3	58,409	27,712	1,036.9
Texas	21,262	11,485	5,971	175.9	19,791	9,884	481.7	58,996	31,790	1,099.2	90,272	47,645	1,756.8
Utah	508	7,342	5,556	129.2	2,461	1,837	70.4	7,932	6,096	82.2	17,735	13,489	281.8
Vermont	1,334	3,944	1,972	40.9	1,803	901	19.0	7,068	3,577	45.1	12,815	6,450	105.0
Virginia	6,782	12,394	5,977	183.2	4,552	2,275	103.4	33,884	16,172	226.5	50,830	24,424	513.1
Washington	1,591	20,584	10,449	277.2	4,137	2,136	96.2	16,644	8,836	119.8	41,365	21,421	493.2
West Virginia	6,625	10,605	5,358	56.9	1,096	562	.8	16,823	8,370	59.5	28,524	14,290	117.2
Wisconsin	4,488	22,064	11,485	247.6	7,848	3,923	204.2	24,717	12,330	216.7	54,629	27,738	668.5
Wyoming	845	6,850	4,451	151.5	1,443	934	85.4	8,575	5,394	159.4	16,868	10,779	396.3
Hawaii	3,045	2,497	1,212	4.3	182	87	.5	11,596	5,510	17.3	14,275	6,809	22.1
District of Columbia	4,320	7,230	3,375	5.0	30	15	.5	12,613	5,814	2.2	19,873	9,204	7.7
Puerto Rico	6,539	10,441	4,809	45.2	989	482	5.2	15,373	7,160	44.0	26,803	12,451	94.4
TOTAL	369,636	767,437	402,722	13,323.0	371,288	188,229	6,727.2	1,377,340	694,647	12,475.4	2,516,065	1,285,598	32,525.6